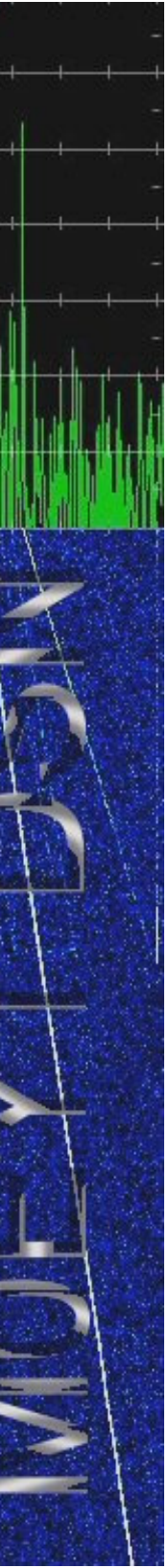
S band & X band Amateur Deep Space Reception

Written and presented by Paul – M0EYT



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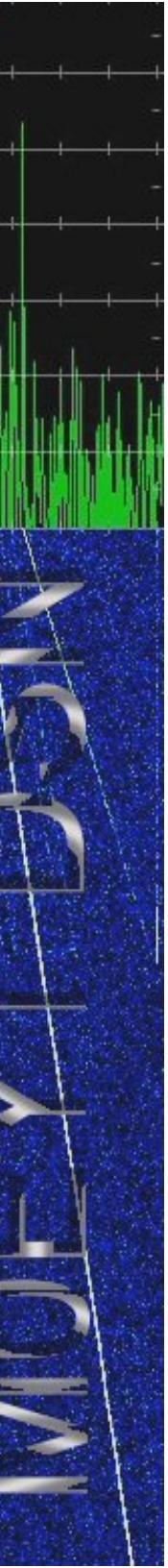
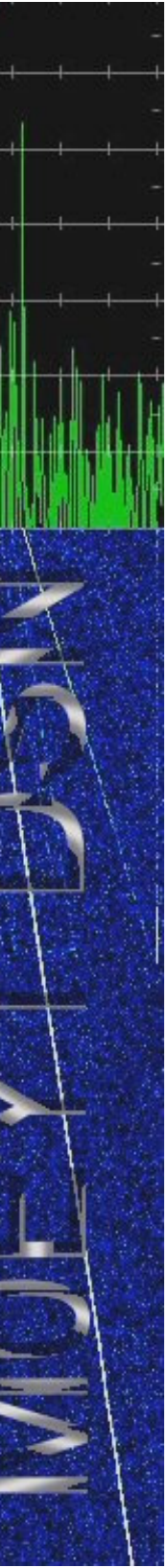
- Introduction
- My background
- The inspiration for this project
- Professional DSN ground stations
- Receive Systems
- Detecting signals
- Typical signals at M0EYT earth station
- Space Craft DX'd so far
- Future
- Questions



Introduction: What is the 'Amateur Deep Space Network' ?

- The Amateur Deep Space Network is a group of dedicated weak signal enthusiasts – The majority of activity is in Europe
- Most of the group members are active microwavers or EME'ers
- A-DSN is concerned with detection of extremely weak signals rather than demodulating science data
- S-Band and X-Band are most common, several people are building receive systems for Ka-Band.
- A yahoo-group 'Amateur-DSN' is used as the focal point for activity, such as detection of newly launched space-craft.



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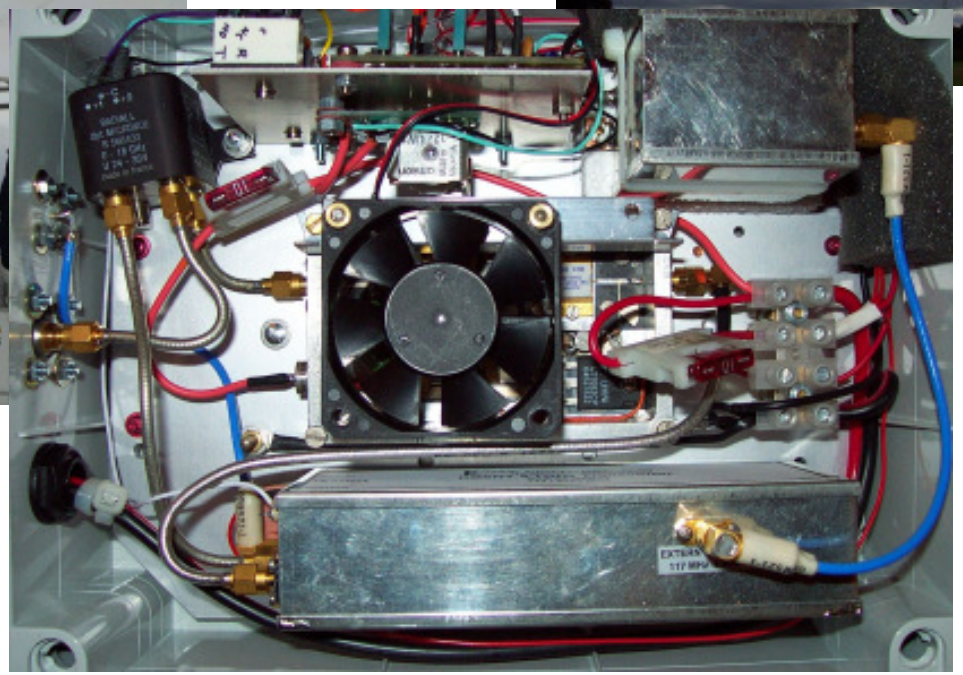
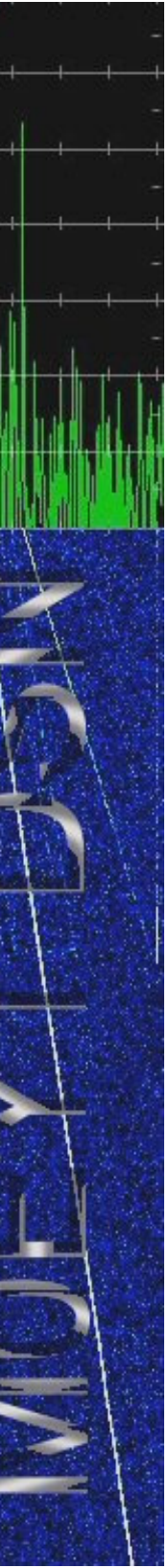
My Background

Ham Radio > 1GHz in frequency
DSN : S, X & Ka receive
Satellite : UHF to Ka band





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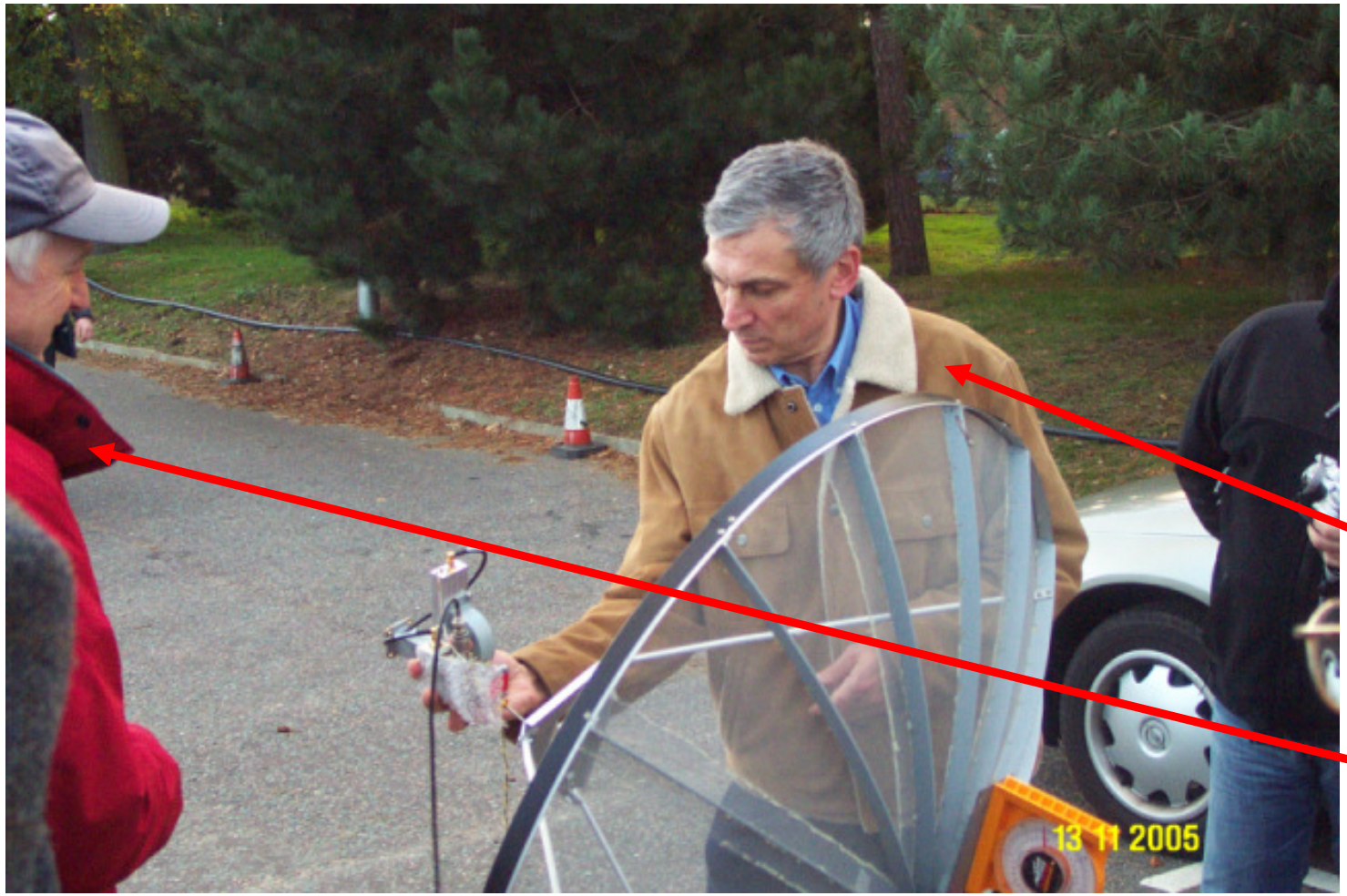
The inspiration for this project

A demo of DSN reception was given at the UK Microwave groups meeting, held at BT Martlesham labs in November 2005



The amateur satellite experts were on hand to give the demo. Freddy ON6UG and James G3RUH

The inspiration for this project

The Venus Express spacecraft was fairly close at 750,000 Miles

Mars Reconnaissance Orbiter was just over 27,000,000 miles awa and still a good signal on the 1 metre dish tha was being used for the demonstration.

Freddy ON6UG is currently working on AMSAT-Phase 5A – The Mars mission

The inspiration for this project

The other piece of inspiration came from NASA;

http://deepspace.jpl.nasa.gov/dsn/faq-data.html#q4
Search
217 blocked
Check
AutoLink
AutoFill
Options
I am an Amateur Radio Operator, can I listen to the data coming from spacecraft?
Unfortunately, no. Spacecraft signals are very weak by the time they reach Earth which is why we need the huge reflector dishes of the Deep Space Network antennas as well as the sophisticated amplifiers and other signal enhancing electronics to hear them. Amateur radio equipment and antennas cannot receive such weak signals.

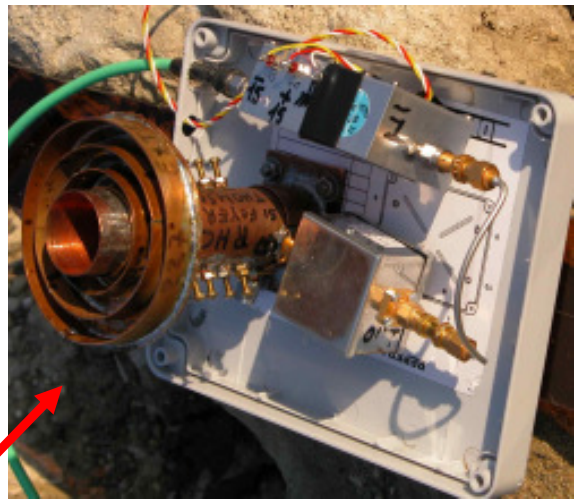
As can be seen from their website FAQ – it clearly states that Amateur Radio operators **cannot** hear such weak signals…

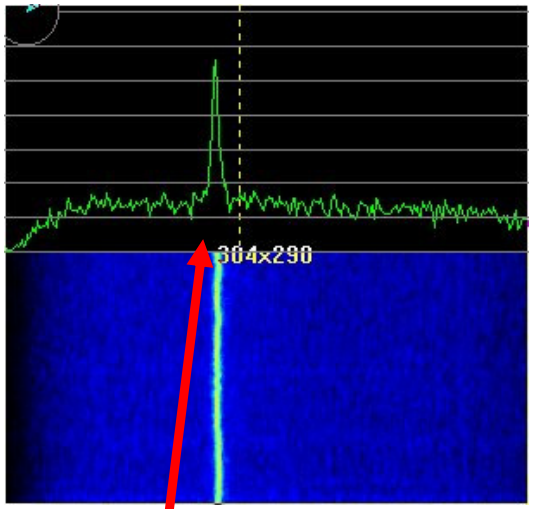
Images copyright NASA / JPL http://deepspace.jpl.nasa.gov

The inspiration for this project

About 30 other hams have also built DSN stations;

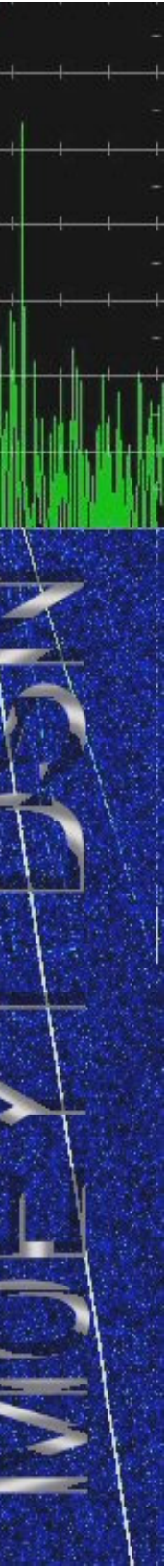
Bertrand F5PL in France





Charlie G3WDG in Hayling Island, UK

Amsat-DL team in Bochum, Germany - Freddy de Guchteneire/ON6UG (Feed system and RF-integration) James Miller/G3RUH (Tracking and antenna control software)



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Professional DSN ground stations

NASA and ESA are both heavy users of DSN frequencies, and have a fair number of DSN receive sites around the world.

NASA has sites at Goldstone, Madrid and Canberra – each with at least 4 antennas, 1X 70m, 2X 34m and 1X 26m dishes.

DSN antennas operate in the 2.1/2.2GHz & 7.1/8.4GHz. NASA are moving towards the 32GHz band for greater transfer rates.

Images copyright NASA / JPL http://deepspace.jpl.nasa.gov

Professional DSN ground stations

The ESA (European Space Agency) also has a fair number of ‘owned’ or ‘borrowed’ DSN tracking antennas, locations include

Cebreros (Spain), New Norcia (Australia), Maspalomas (Spain), Perth (Australia), Kourou (French Guiana), Kiruna (Sweden), Redu (Belgium), Villafranca (Spain)

Typical antenna sizes are 35m, 15m, 12m and 3m

Images copyright ESA http://www.esa.int

Professional DSN ground stations

The gain of a typical DSN antenna is extremely high. Example for the Goldstone 70m antenna (used for tracking the Pioneer probes etc):

Efficiency ~ 65%, Frequency ~8.4GHz

Signal gain 74dB = a gain of 25,118,864.3 over an omni

1 watt of RF at the focal point would result in an ERP of 25MW!

The -3dB beam width of this antenna is around 0.04 degrees!

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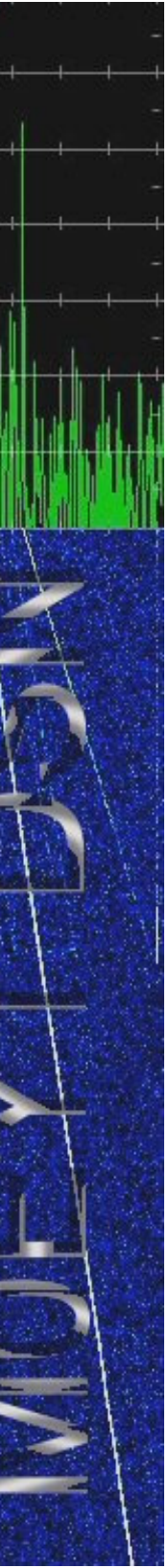

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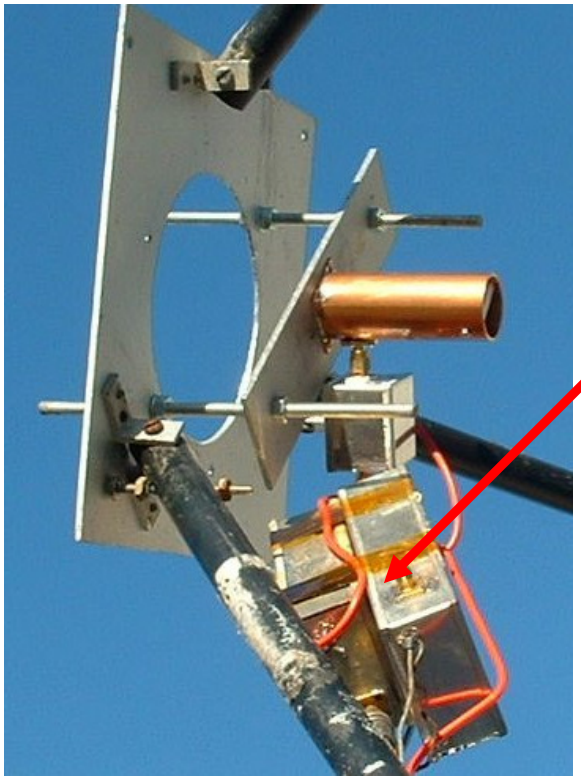
Receive Systems

What X-Band equipment is available ‘off the shelf’ ?

DB6NT equipment:
Regarded as the leader in amateur microwave communications equipment

–Images copyright DB6



Images copyright G3WDG

G3WDG or the RSGB microwave components service also has equipment in development.

Receive Systems

Down-converters: why use them?

- 8.4GHz is not easy to send down a long coaxial cable
- Far easier to send an lower frequency IF to the receiver
- Same principle as the ‘LNB’ on your Direct-TV dish
- Not really needed for S-Band 2200MHz-2300MHz

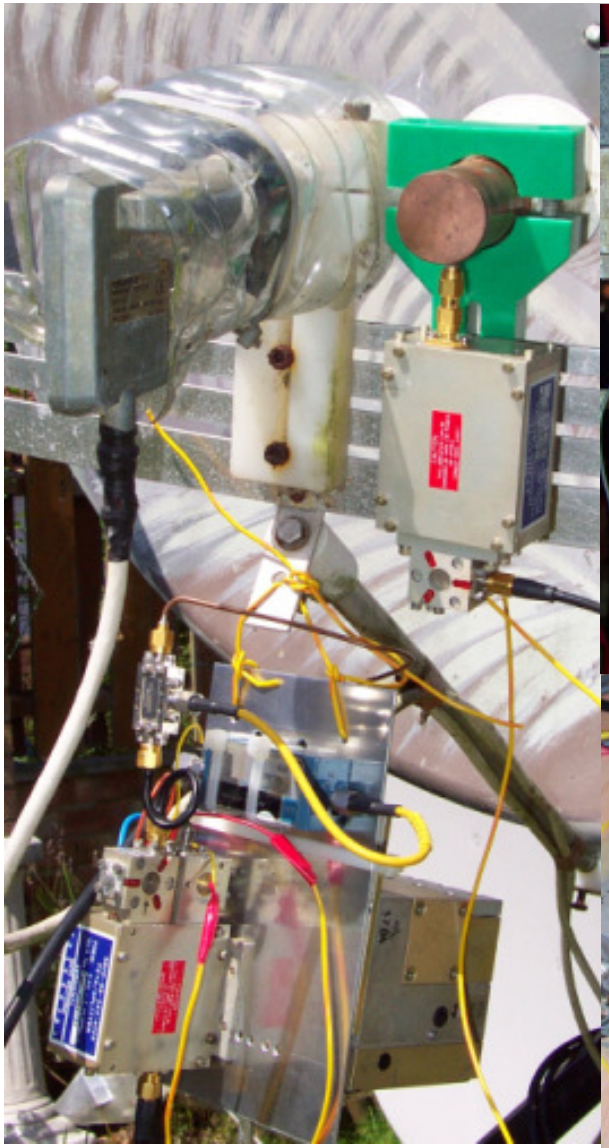
How does it work ?

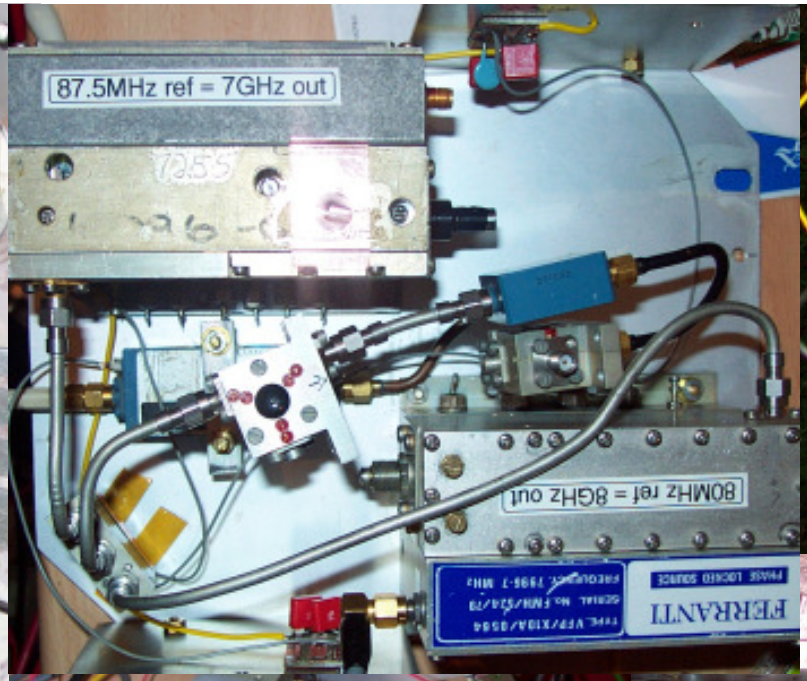
Incoming RF is amplified then filtered

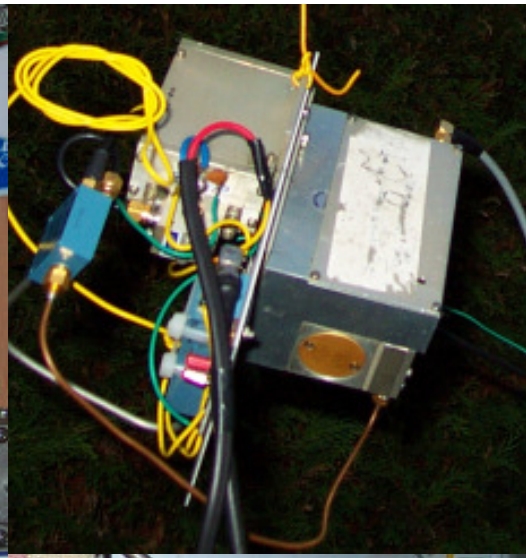
- A local oscillator generates a signal which is mixed with the incoming RF resulting in two mixing products F+LO and F-LO.
- The F–LO is filtered off and amplified before being sent down coax to the receiver.
- Typical IF is 100MHz – 2GHz

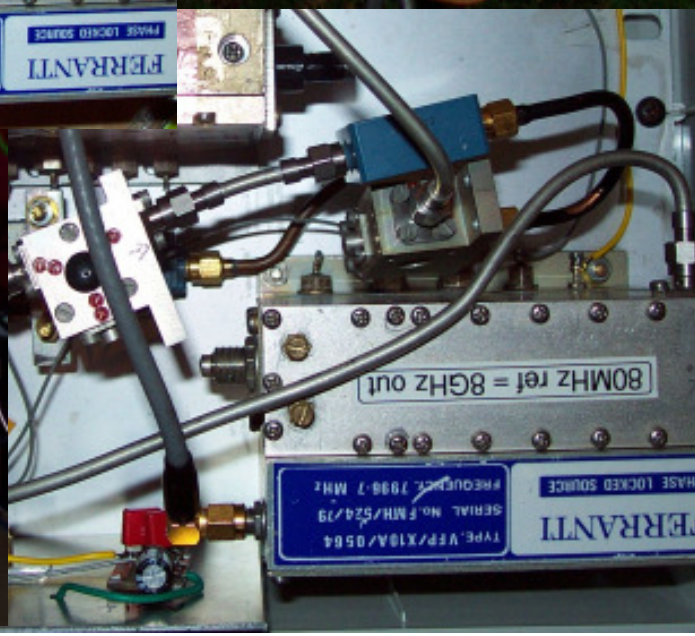
Receive Systems

The M0EYT down converter : ‘N’ intermediate versions…

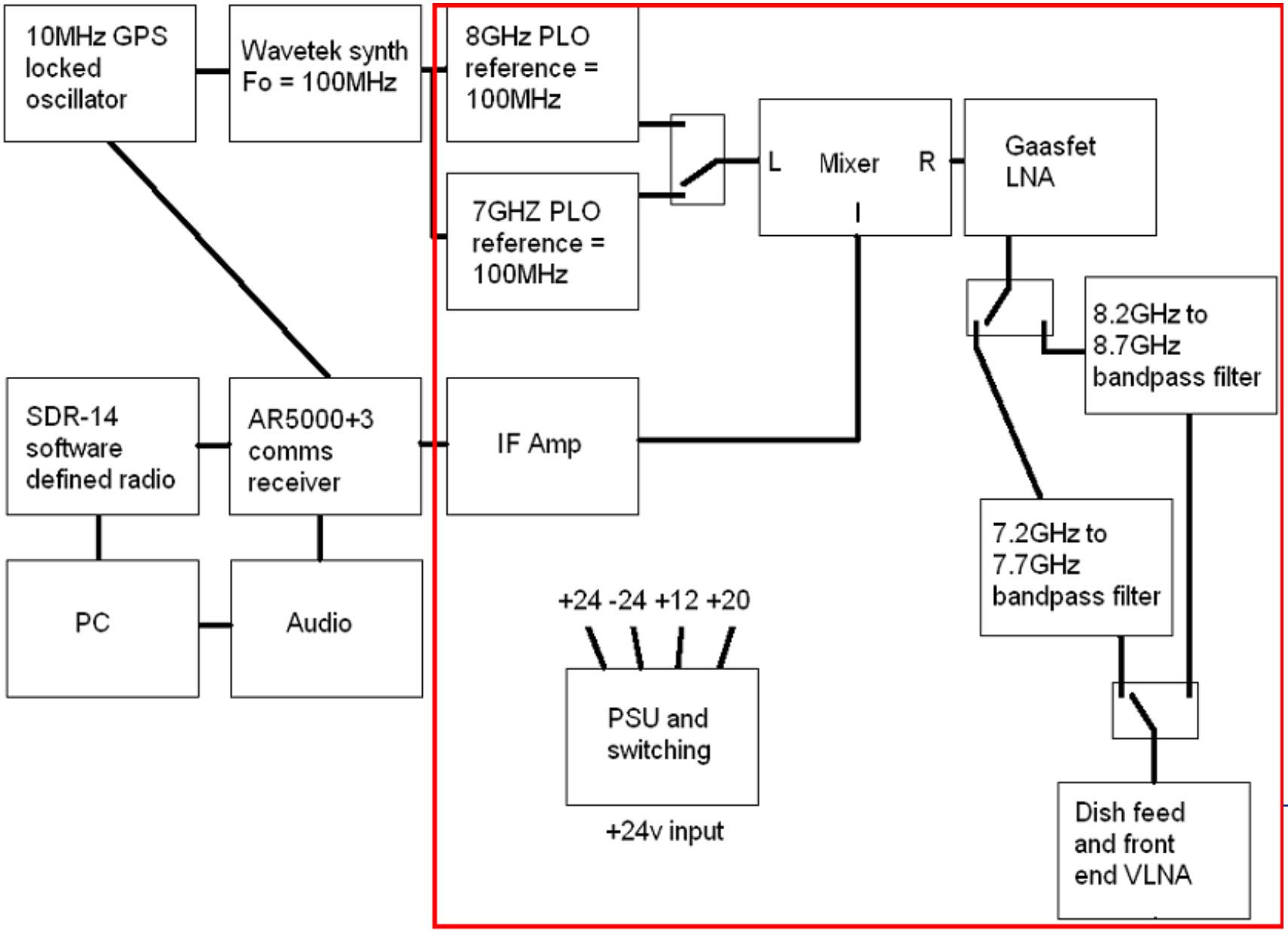




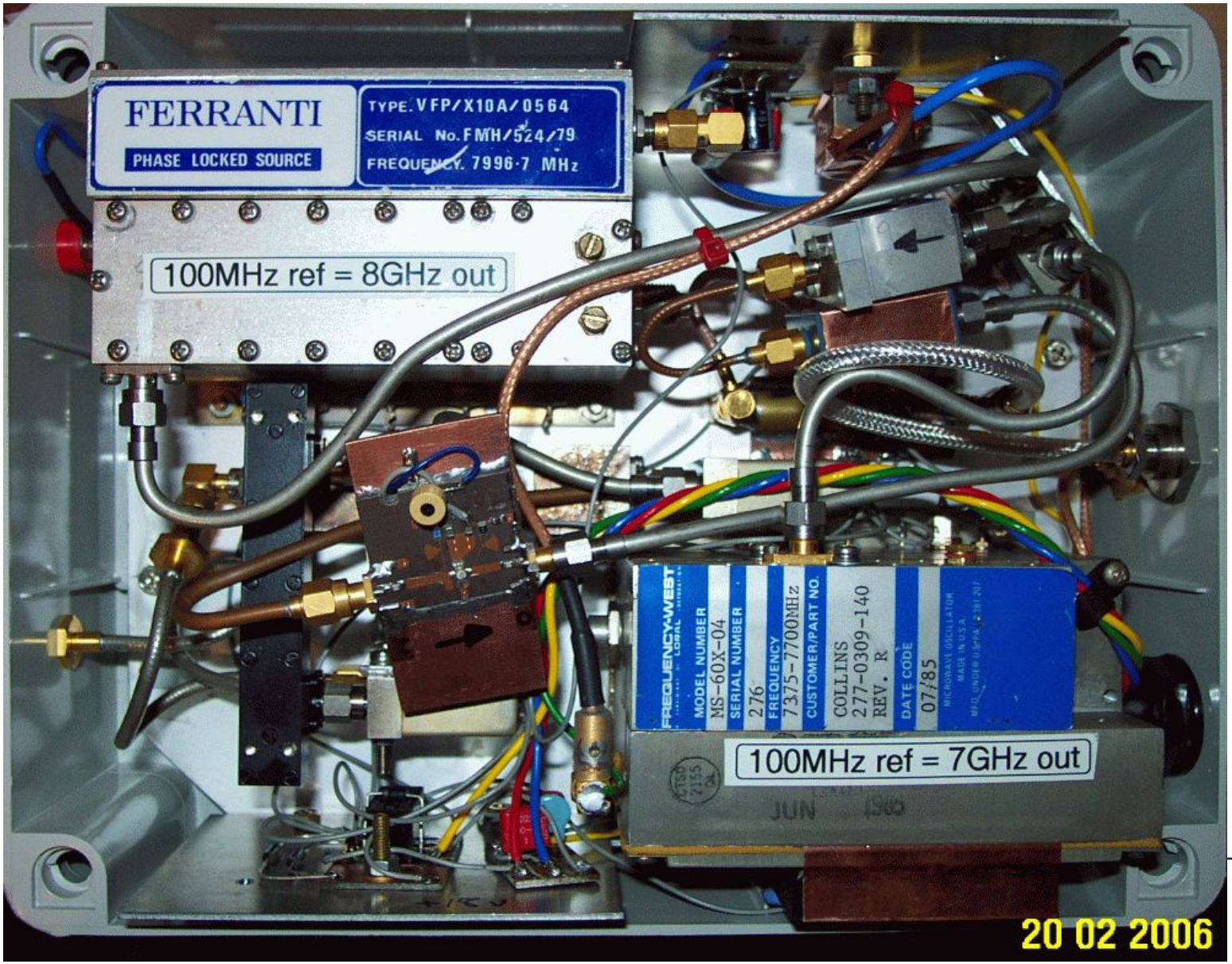




The M0EYT down converter : “final?” build block diagram

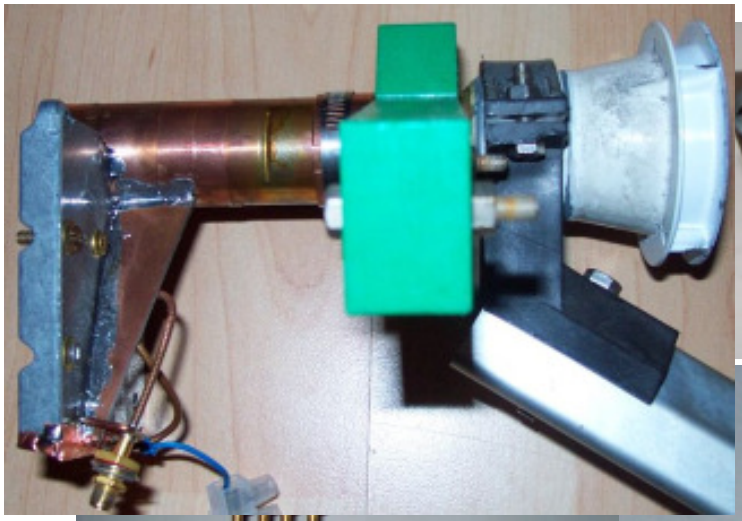
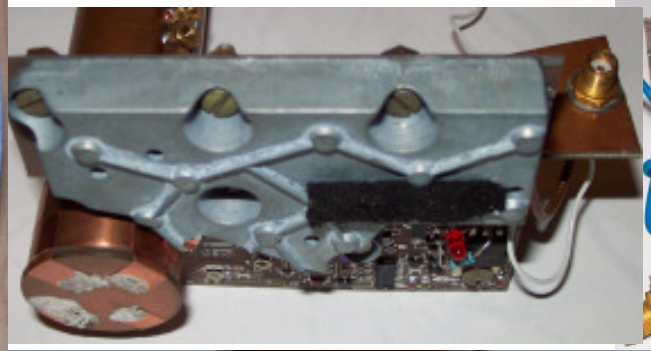
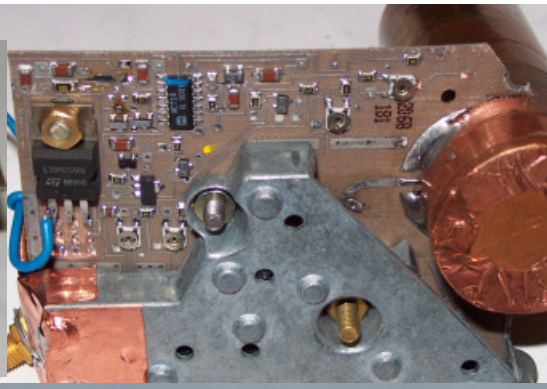
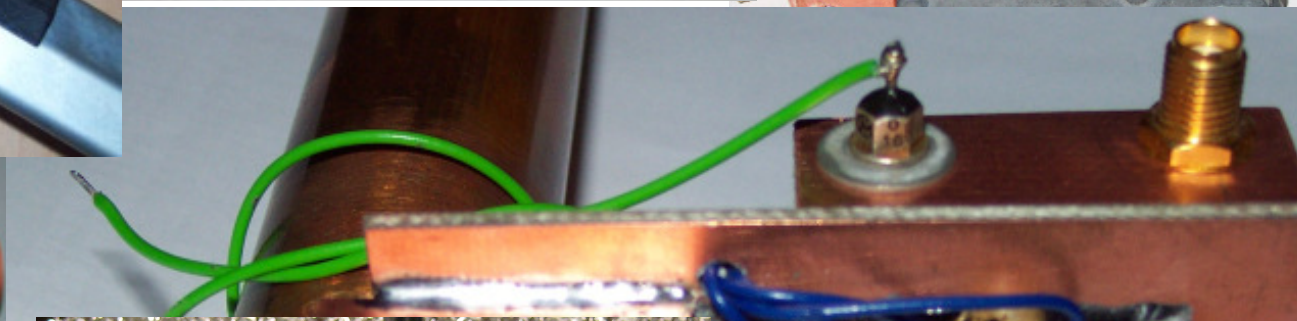
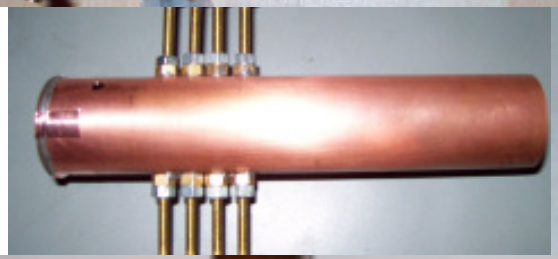


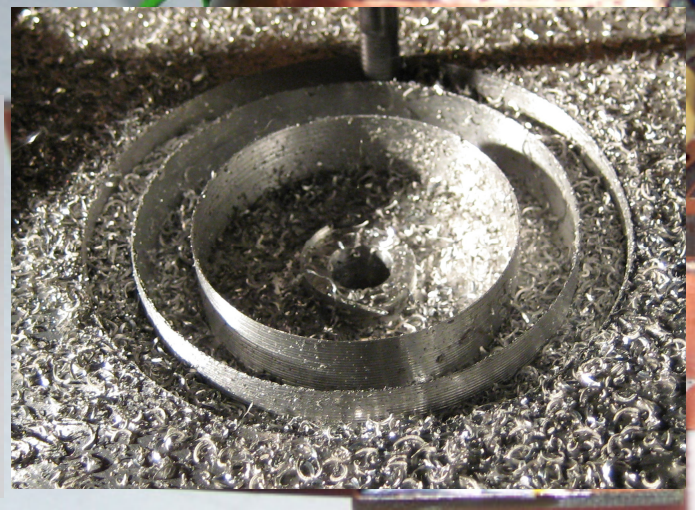
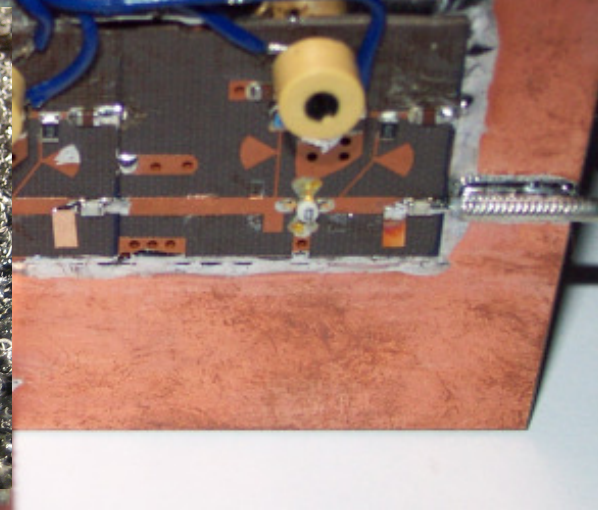
The M0EYT down converter : final build hardware

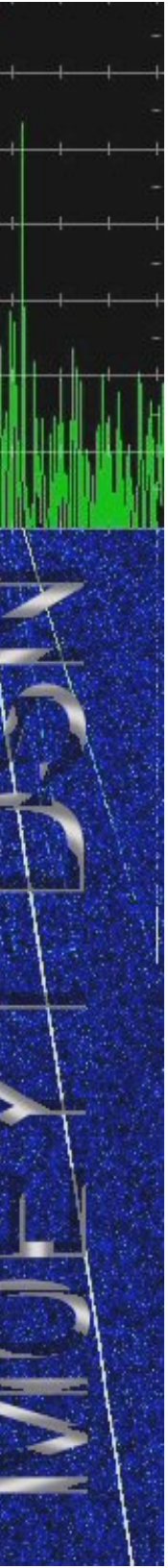


Receive Systems

The dish feed and LNA also went through a few iterations:



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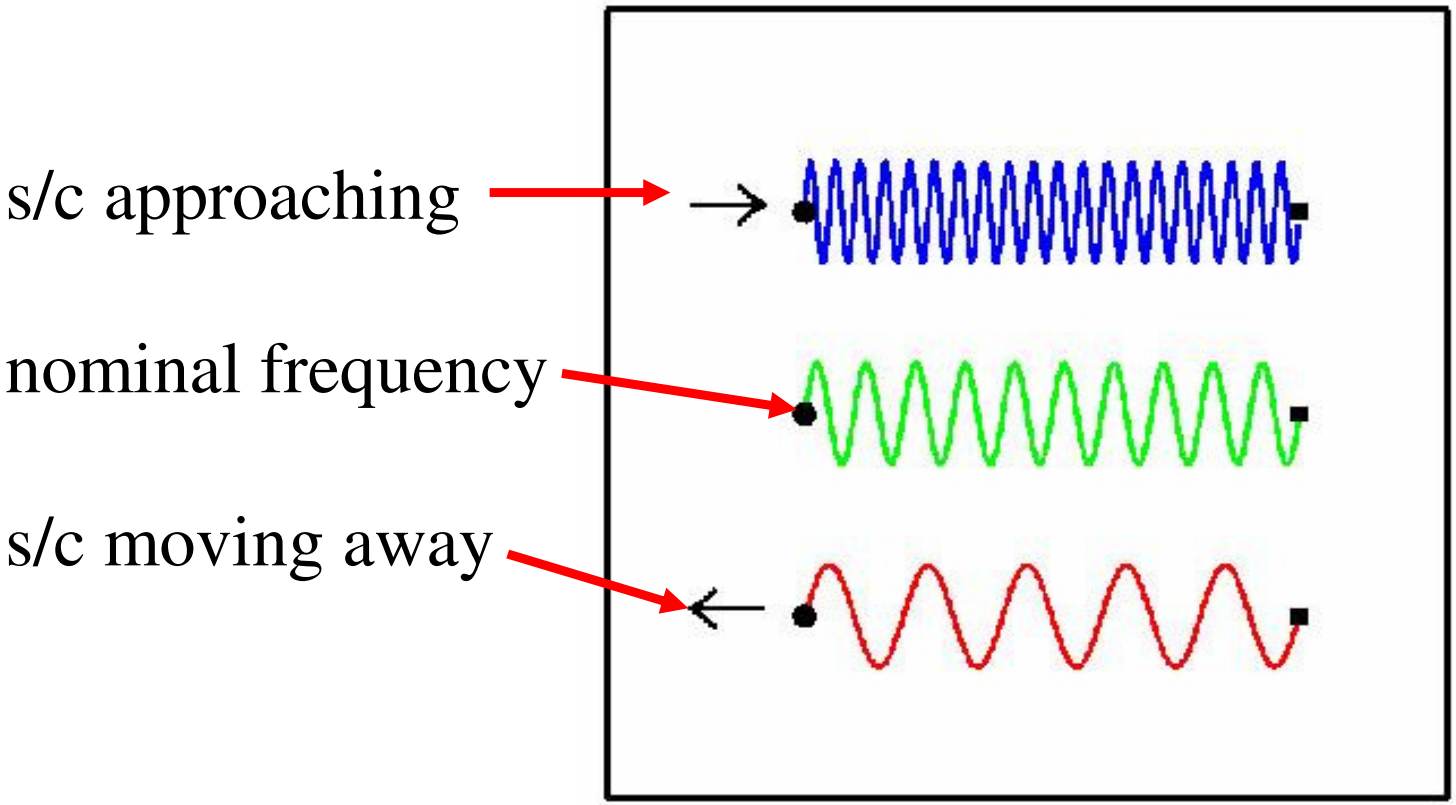
Detecting signals

Several technical issues have to be addressed first:

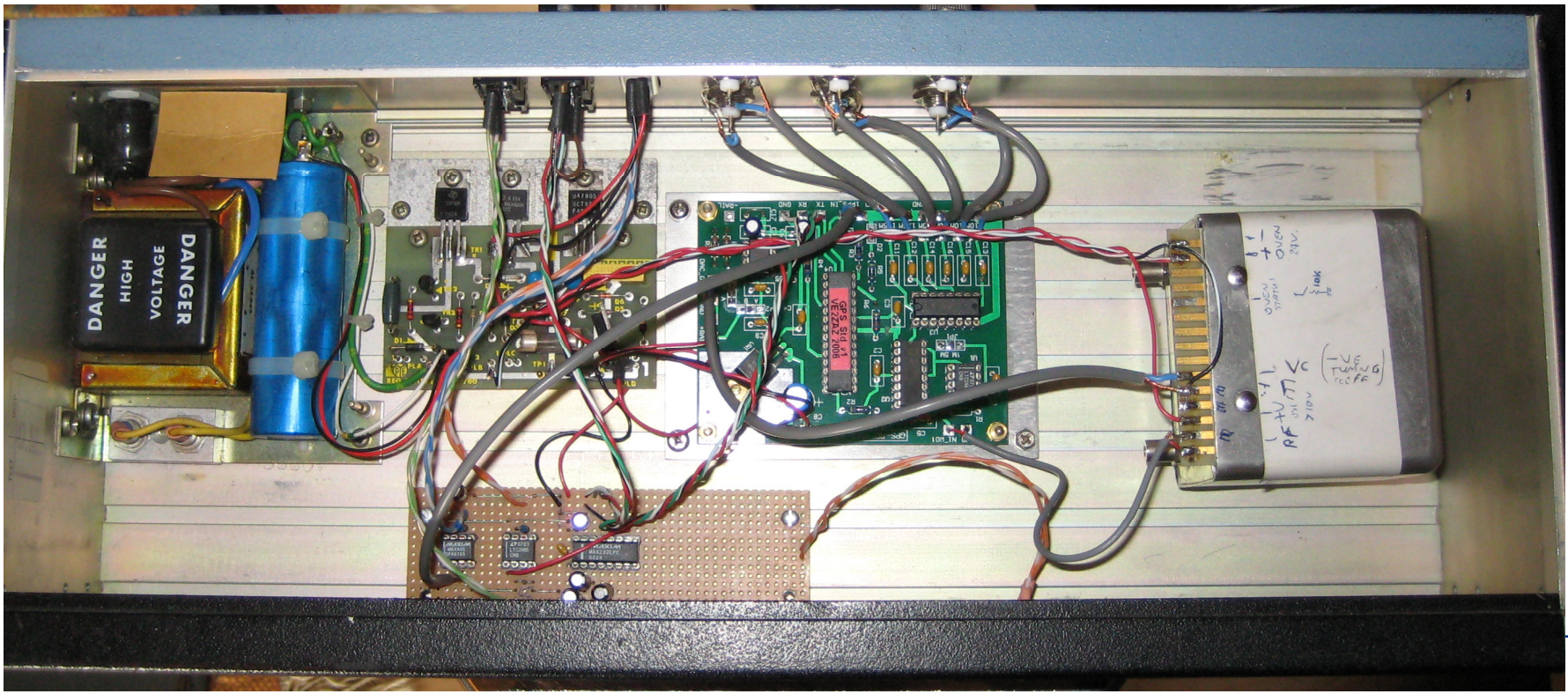
- Precise frequency of the signals that you are trying to receive
- Computing the direction of the space craft
- Factor in the Doppler shift caused by the relative movement



Detecting signals

Frequency references: Since the signals are extremely weak, its important to know that you are tuning to the correct frequency at 8.4GHz

GPSDO's are easy to build with solutions such as the VE2ZAZ

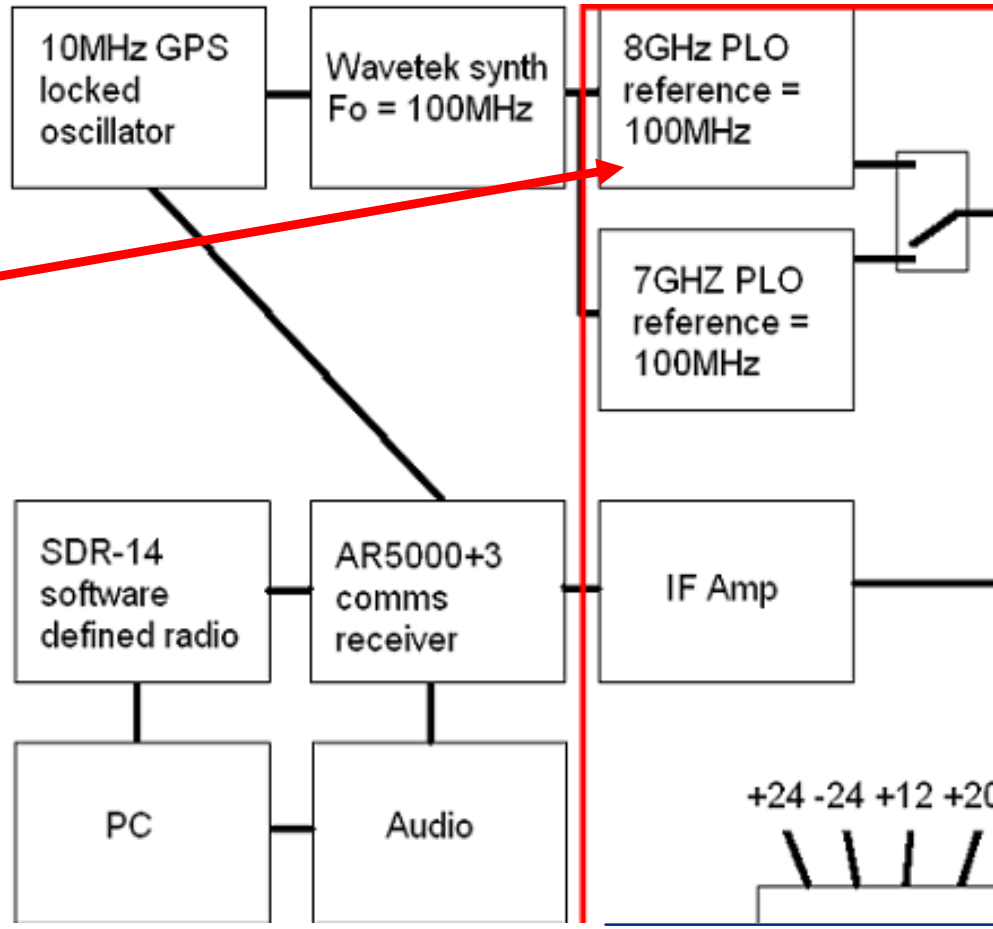


Detecting signals

Frequency references:

10MHz from the GPSDO is distributed to the Wavetek synthesiser and the communications receiver.

The 8GHz LO is made by locking a 1.6GHz cavity oscillator to the 100MHz signal from the Wavetek. The 1.6GHz signal is then multiplied by 5 to generate 8 GHz



Detecting signals

The AR5000 communications receiver used during the DSN reception attempts.

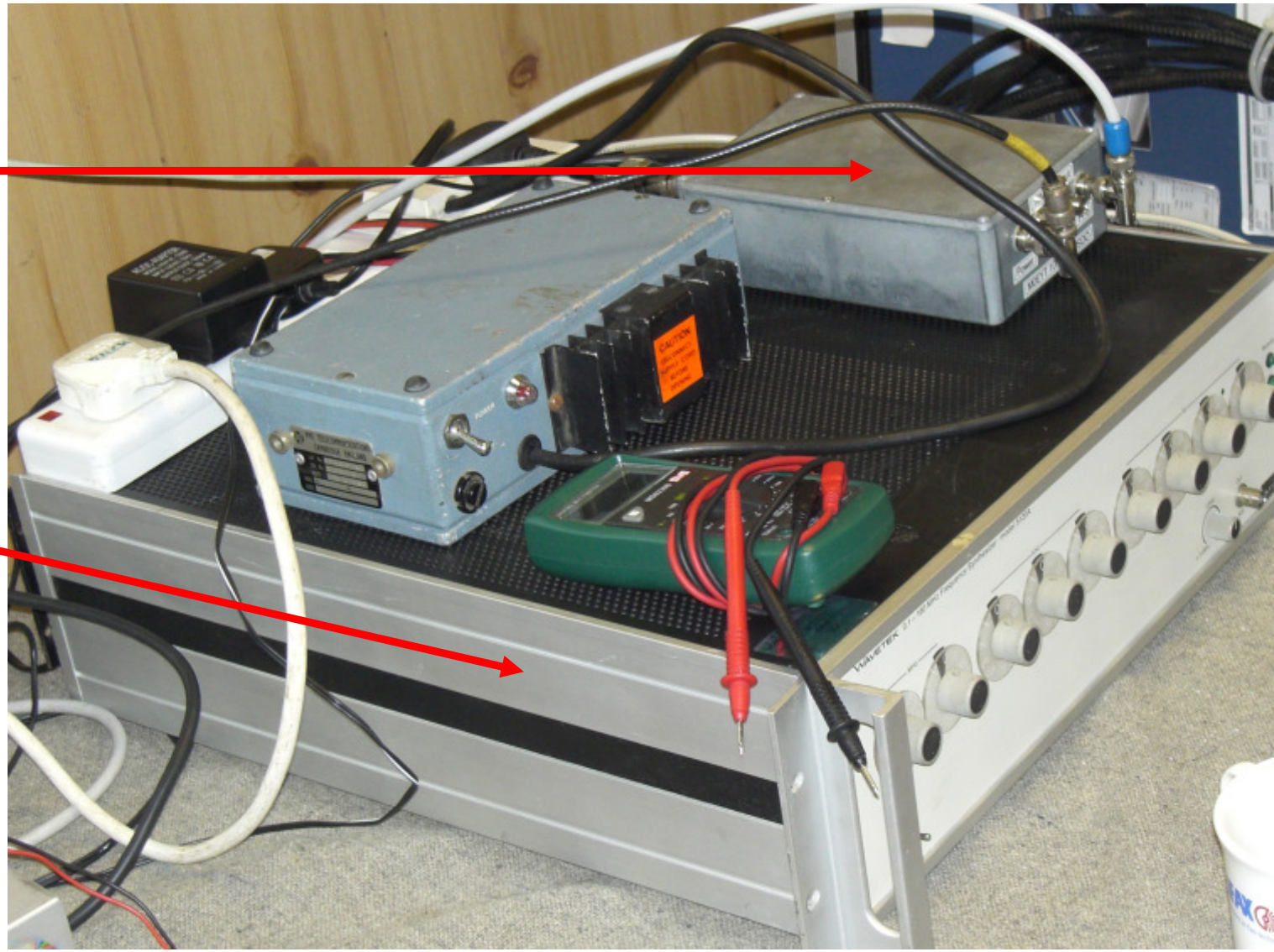
On top is the SDR-14 software radio.

GØNZO Photo

Detecting signals

10MHz GPS locked oscillator

Wavetek synthesiser output = 100MHz



G0NZO Photo

Detecting signals

Pointing the antenna:
NASA have a wonderful tool ‘JPL Horizons’ -
http://ssd.jpl.nasa.gov/horizons.html

```
*******************************************************************************
Start time      : A.D. 2008-Oct-24 00:00:00.0000 UT
Stop  time      : A.D. 2008-Oct-25 00:00:00.0000 UT
Step-size       : 10 minutes
*******************************************************************************
Target pole/equ : IAU_MARS                      {East-longitude -}
Target radii    : 3396.2 x 3396.2 x 3376.2 km   {Equator, meridian, pole}
Center geodetic : 275.606400,33.7528442,-.0013633 {E-lon(deg),Lat(deg),Alt(km)}
Center cylindric: 275.606400,5308.54202,3523.6818 {E-lon(deg),Dxy(km),Dz(km)}
Center pole/equ : High-precision EOP model      {East-longitude +}
Center radii    : 6378.1 x 6378.1 x 6356.8 km   {Equator, meridian, pole}
Target primary  : Sun                           {source: DE405+DE406}
Interfering body: MOON (Req= 1737.400) km       {source: DE405}
Deflecting body : Sun, EARTH                    {source: DE405}
Deflecting GMs  : 1.3271E+11, 3.9860E+05 km^3/s^2
Atmos refraction: NO (AIRLESS)
RA format       : HMS
Time format     : CAL
RTS-only print  : NO
EOP file        : eop.081022.p090113
EOP coverage    : DATA-BASED 1962-JAN-20 TO 2008-OCT-22. PREDICTS-> 2009-JAN-12
Units conversion: 1 AU= 149597870.691 km, c= 299792.458 km/s, 1 day= 86400.0 s
Table cut-offs 1: Elevation (-90.0deg=NO ),Airmass (>38.000=NO), Daylight (NO )
Table cut-offs 2: Solar Elongation (  0.0,180.0=NO )
*******************************************************************************************************************
 Date__(UT)__HR:MN     Azi_(a-appr)_Elev            delta      deldot    1-way_LT    S-O-T /r     S-T-O
*******************************************************************************************************************
$$SOE
 2008-Oct-24 00:00 A   255.2002  -6.5916 2.50214259225454   0.9655140  20.809685  12.6103 /T   8.0712
 2008-Oct-24 00:10 A   256.5214  -8.6097 2.50214646465870   0.9653440  20.809718  12.6082 /T   8.0699
 2008-Oct-24 00:20     257.8322 -10.6389 2.50215033496055   0.9644657  20.809750  12.6061 /T   8.0686
 2008-Oct-24 00:30     259.1355 -12.6782 2.50215420031977   0.9628796  20.809782  12.6040 /T   8.0673
 2008-Oct-24 00:40     260.4346 -14.7263 2.50215805790106   0.9605877  20.809814  12.6018 /T   8.0660
 2008-Oct-24 00:50     261.7326 -16.7822 2.50216190487958   0.9575932  20.809846  12.5997 /T   8.0647
```

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Detecting signals

Determining the frequency to tune:

DSN tracking spreadsheet by Paul M0EYT Mission Name / JPL Horizons ID	Info OK ?	DSN Channel	Spacecraft TX frequency (MHz)	Velocity (KM/s)	Doppler corrected (MHz)	Doppler shift (KHz)	Tuning Freq (MHz)	Comments	Launch Da DD/MM/YYY
Last updated		3	8400.061729	0.000000	8400.061729	0.000000			
23/10/2008 12:08		4	8401.419752	0.000000	8401.419752	0.000000			01/08/200
		4	8401.577700	5.591712	8401.420994	-156.705747			
Phoenix Lander http://phoenix.lpl.arizona.edu/	Y	5	8402.777700	5.543651	8402.622319	-155.381053	8402.614319		
		6	8403.977700	5.624661	8403.820026	-157.674165			01/08/200
		6	8404.135802	0.000000	8404.135802	0.000000			
		7	8405.493825	0.000000	8405.493825	0.000000			
Mars Odyssey -53 (Mars 499)	Y	8	8406.851853	1.552799	8406.808309	-43.543953			07/04/200
Hayabasu -130 / Ulysees -55	Y	9	8408.209877	-6.715989	8408.398239	188.361799			09/05/200
		10	8409.567903	0.000000	8409.567903	0.000000			
Pioneer -24 / -23		11	8410.925927	0.000000	8410.925927	0.000000			
Pioneer -24 / -23		12	8412.283950	0.000000	8412.283950	0.000000			
Spitzer space telescope -79	Y	13	8413.626490	0.026333	8413.625751	-0.739023			25/08/200
		13	8413.641977	0.000000	8413.641977	0.000000			
Voyager -31-32 / Stardust -29	Y	14	8415.000000	18.851122	8414.470860	-529.140043			
		15	8416.358023	0.000000	8416.358023	0.000000			
		16	8417.716050	0.000000	8417.716050	0.000000			
Venus Exp -248 (Venus 299)	Y	17	8419.074073	-6.131067	8419.246252	172.178791	8419.251252	add 5KHz	09/11/200
Mars Exp -41 (Mars 499) / Voyager -31 -32	Y	18	8420.432097	1.552799	8420.388483	-43.614293	8420.311483	doppler adjust	02/06/200
Rosetta -226	Y	19	8421.790123	9.606914	8421.520245	-269.878082	8421.517245	corrected freq	02/03/200
		20	8423.148147	0.000000	8423.148147	0.000000			
Kepler http://kepler.nasa.gov/	Y	20	8423.331100	0.000000	8423.331100	0.000000		32.16029GHz	01/10/200
MGS (Mars 499)	Y	20	8423.177000	1.552799	8423.133371	-43.628510			07/11/199
Kepler http://kepler.nasa.gov/	Y	21	8424.506175	0.000000	8424.506175	0.000000		32.16629GHz	
		22	8425.681100	0.000000	8425.681100	0.000000			01/10/200
Magellan		22	8425.864198	0.000000	8425.864198	0.000000			
Mars Pathfinder / Cassini		23	8427.222221	23.301314	8426.567217	-655.004295			
Giotto -78		24	8428.580248	0.000000	8428.580248	0.000000			

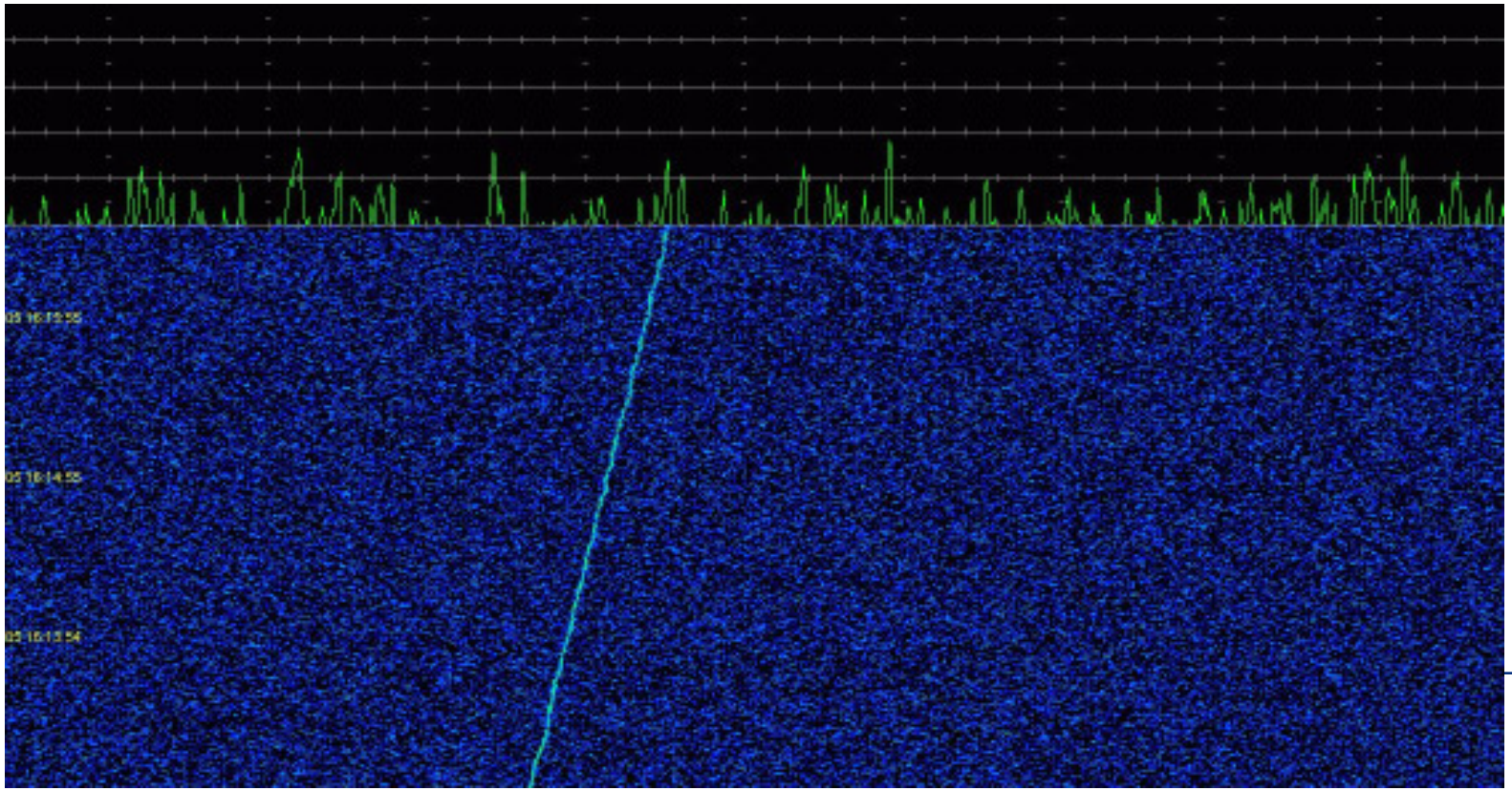
http://www.uhf-satcom.com/DSN.xls

Detecting signals

Following those steps, we now have the parameters required:

BUT, How do you tune the signal in if you cannot hear it?

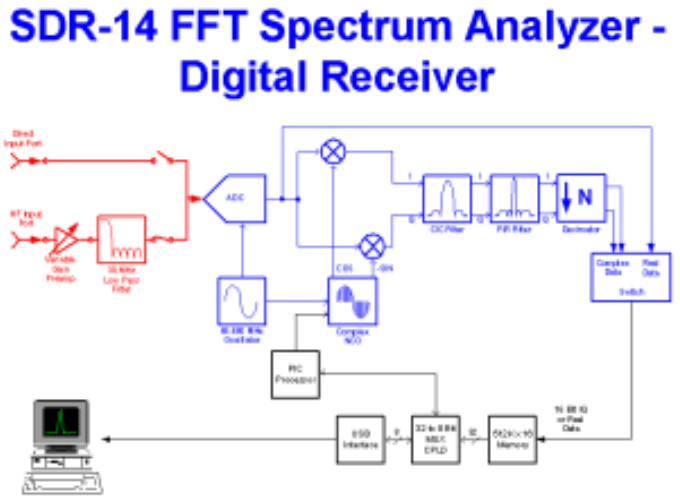
Answer: FFT and SDR



Detecting signals

FFT'ing the audio is ok if the signal is in the RX passband…

Doppler and tweaks in frequency at the spacecraft can mean you could miss the signal completely – solution: a SDR



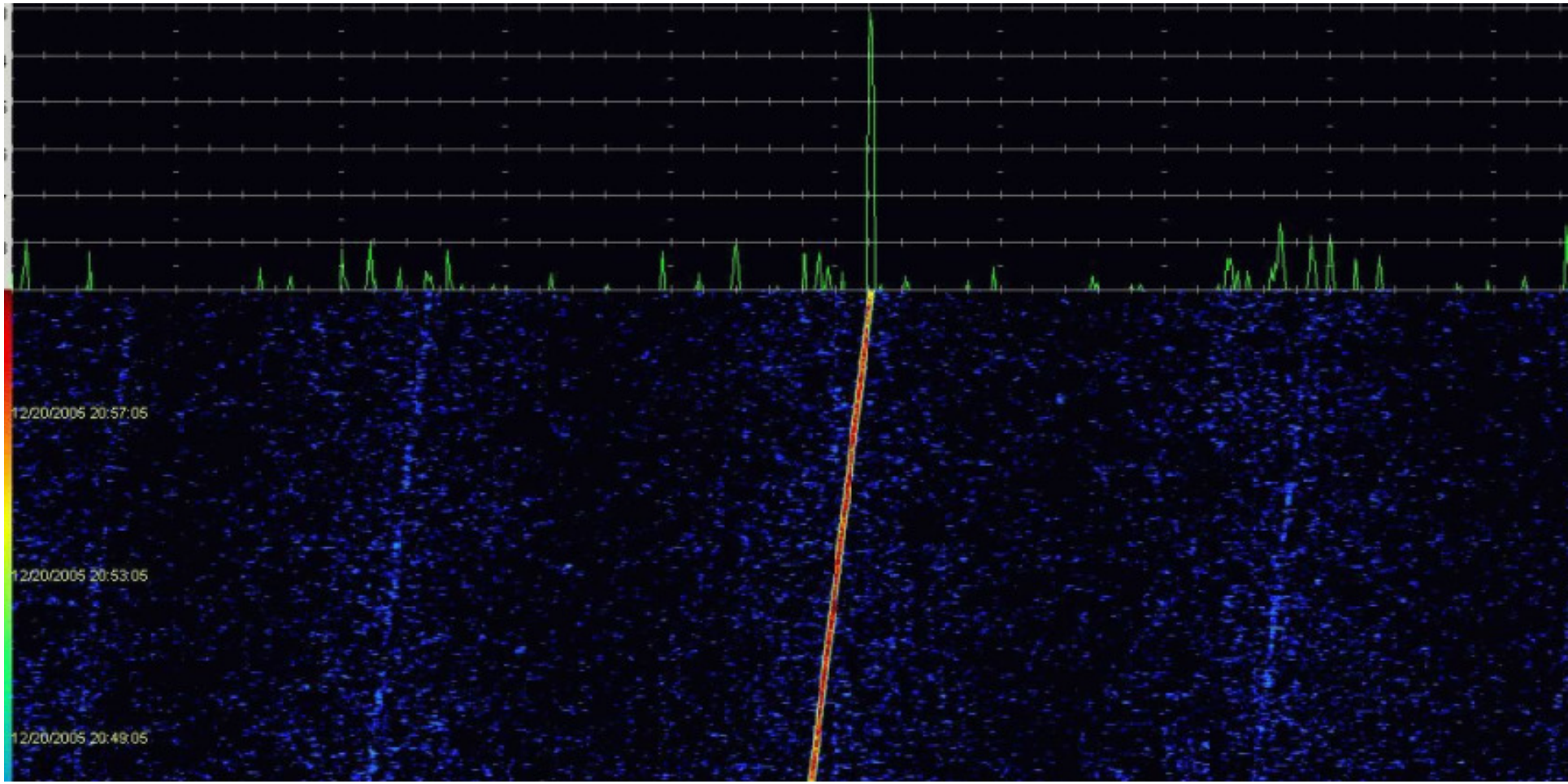
The SDR-14 can 'look' at 30MHz of RF at once – practical bandwidth to increase FFT resolution is 10 to 25 KHz. The SDR looks at the 10.7MHz IF of the AR5000 receiver.

Images copyright RF-Space http://www.rfspace.com

Detecting signals

The result with the SDR looking at 25KHz of RF:

An easy copy of the MRO tracking beacon at 53,248,299.48 mile



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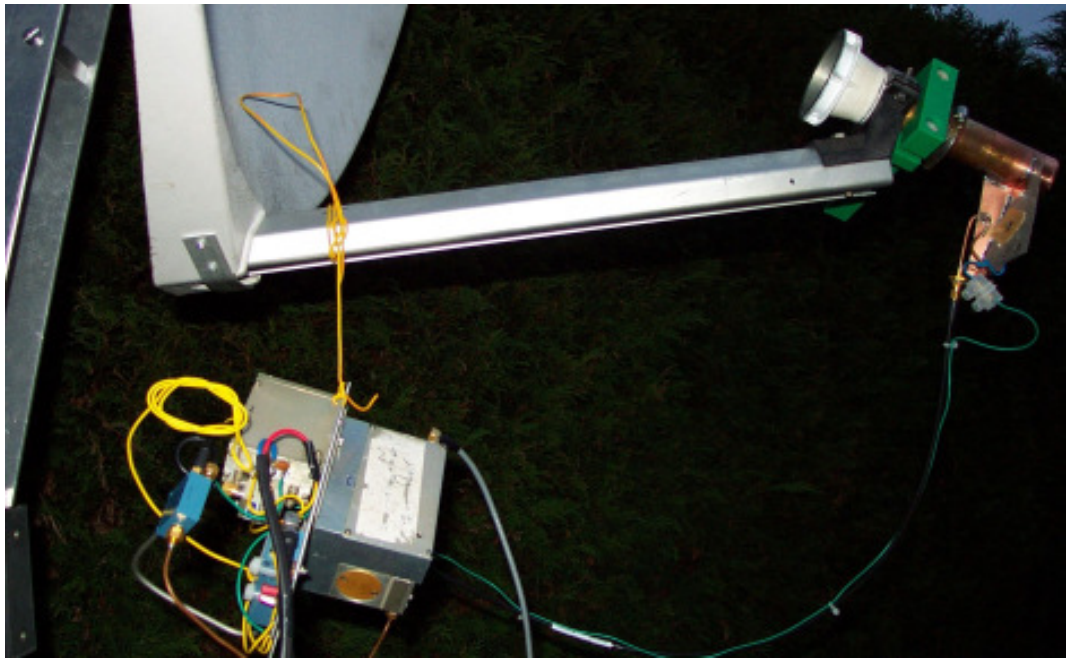
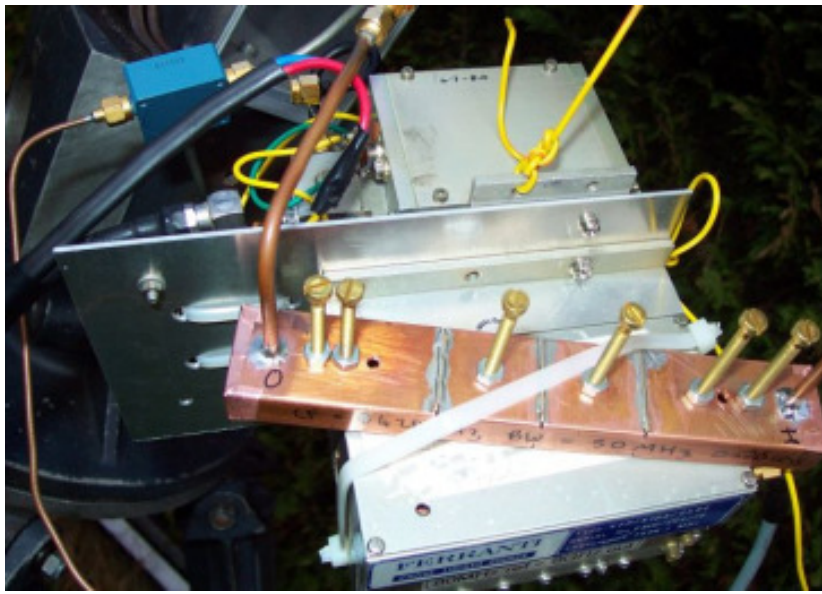
Typical signals at M0EYT earth station

First DSN carrier copied from the Venus Express spacecraft launched 9th November 2005.

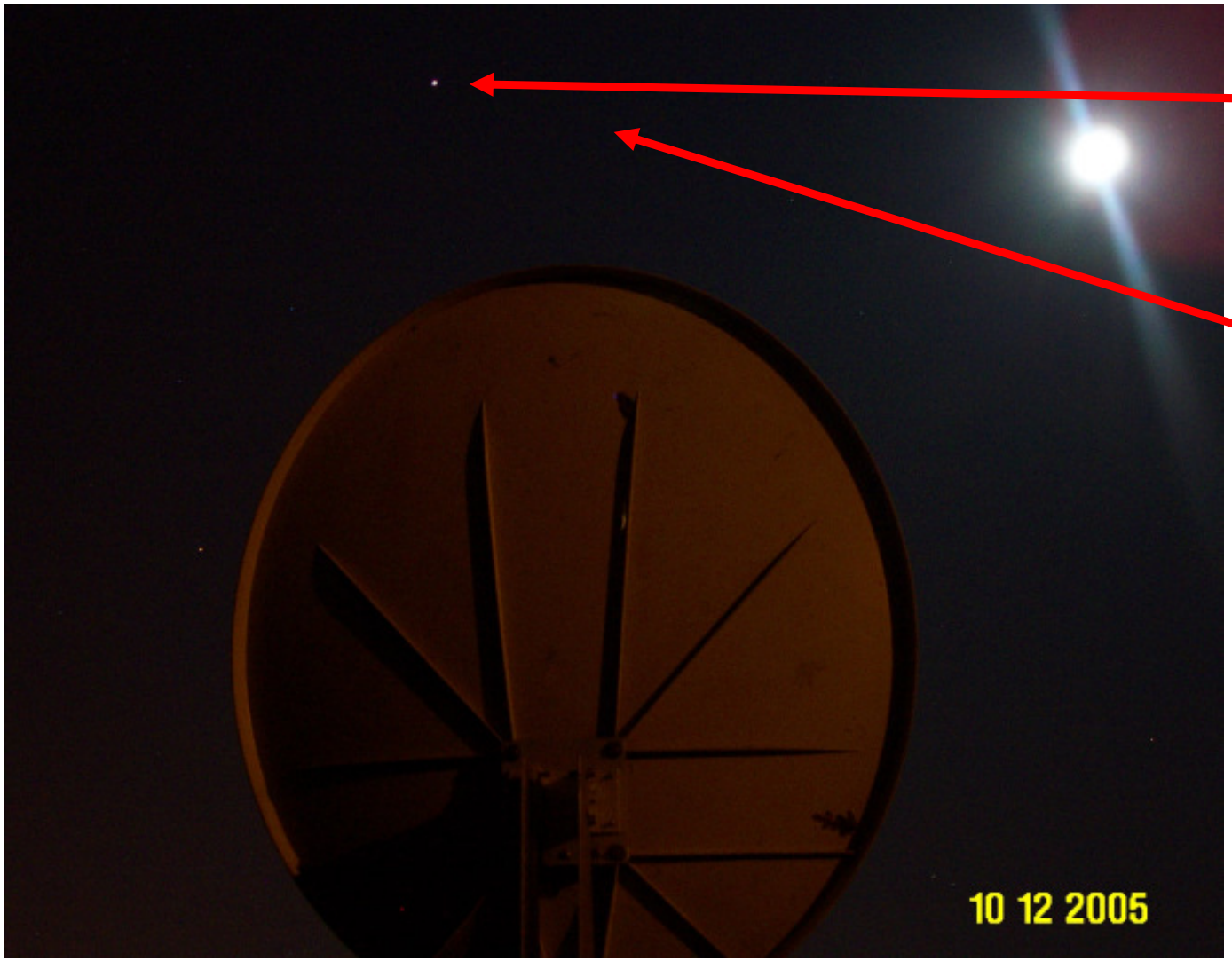
Signals received 5th of December 2005 at 15:50UTC with the s/c only 4,032,732.96 miles away





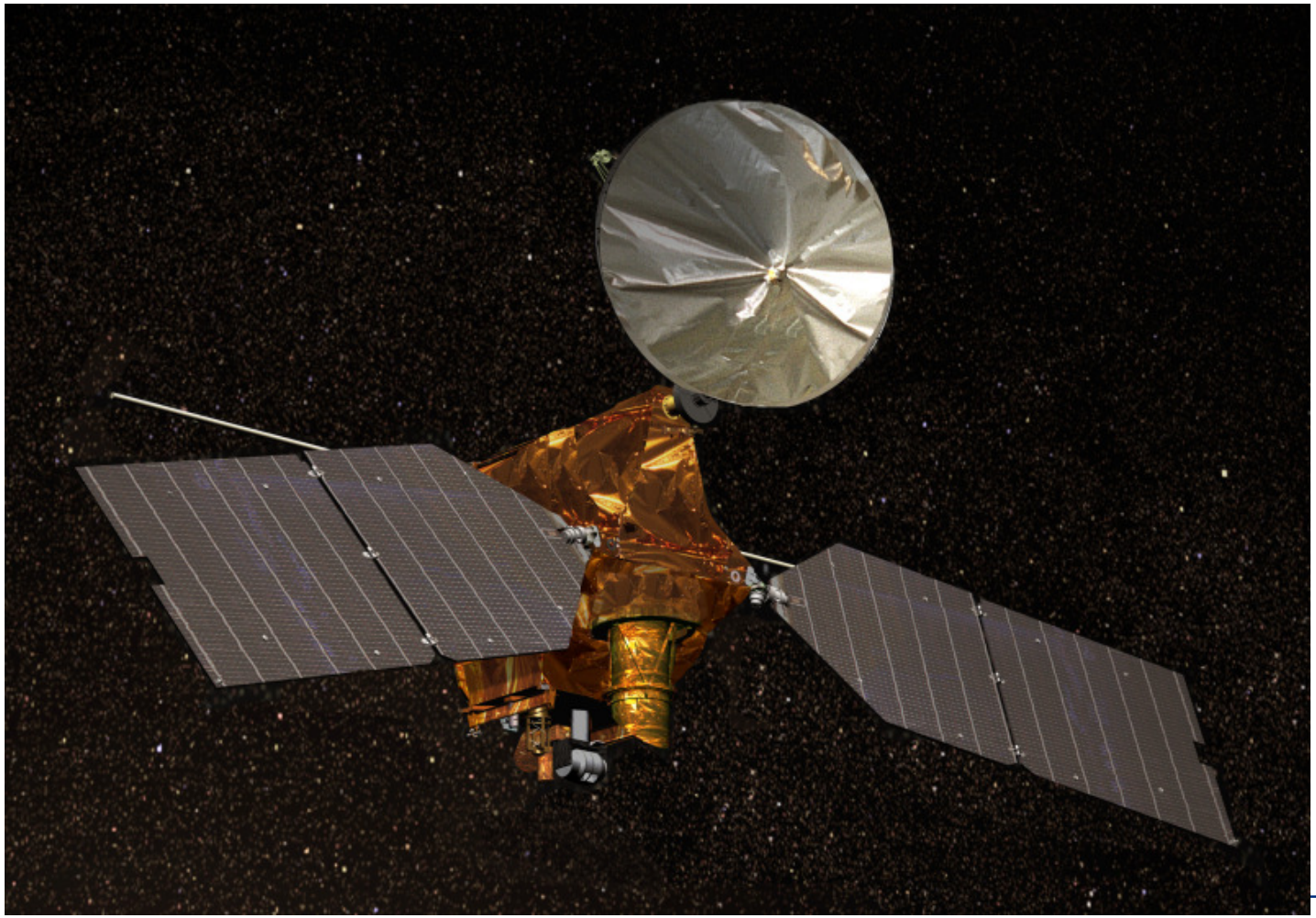
Typical signals at M0EYT earth station

After VEX – MRO was the next target at 45,151,194 miles from Earth



Typical signals at M0EYT earth station

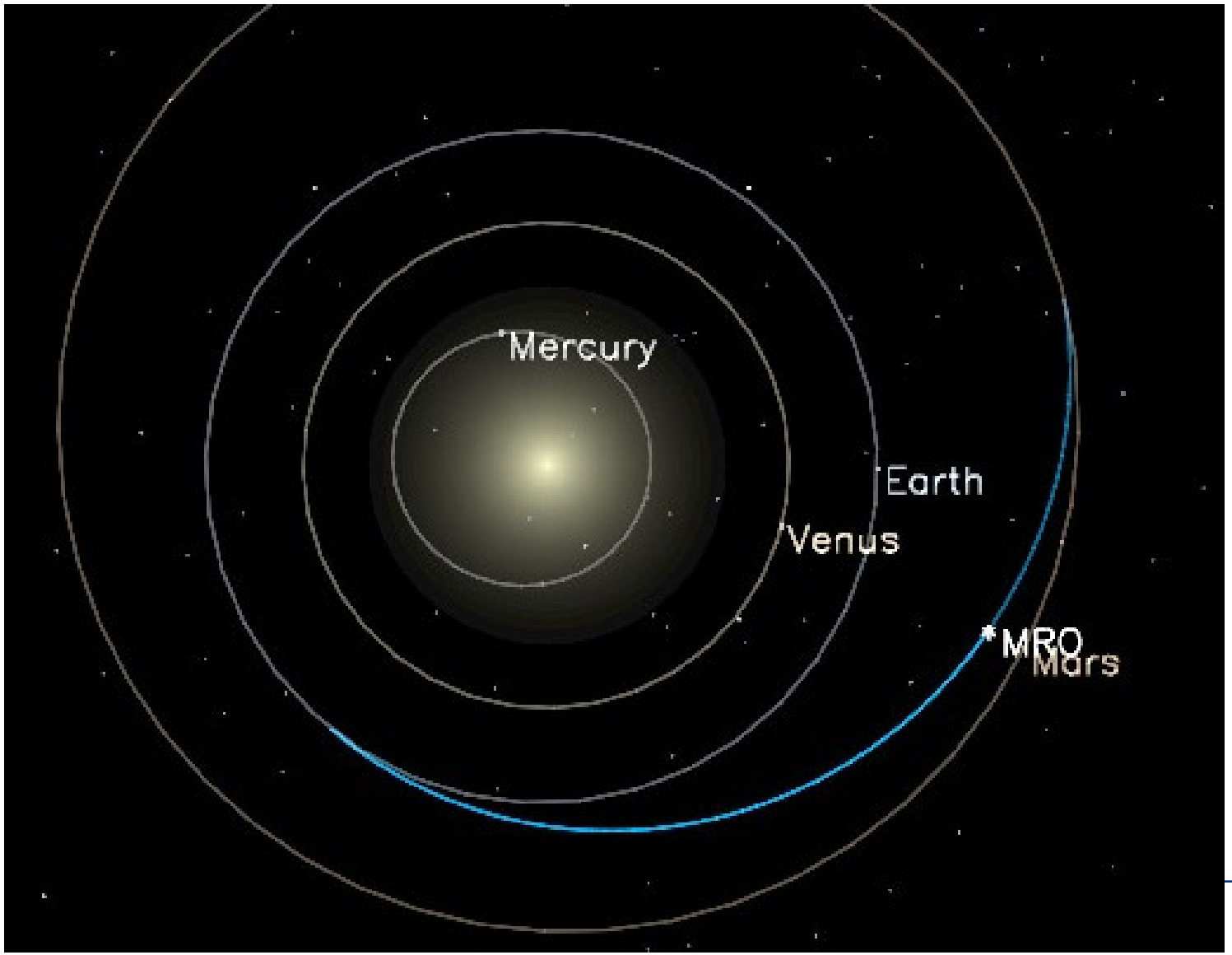
MRO was launched on the 12th of August 2005 from Cape Canaveral Air Force Station in the USA.



Courtesy NASA/JPL-Caltech

Typical signals at M0EYT earth station

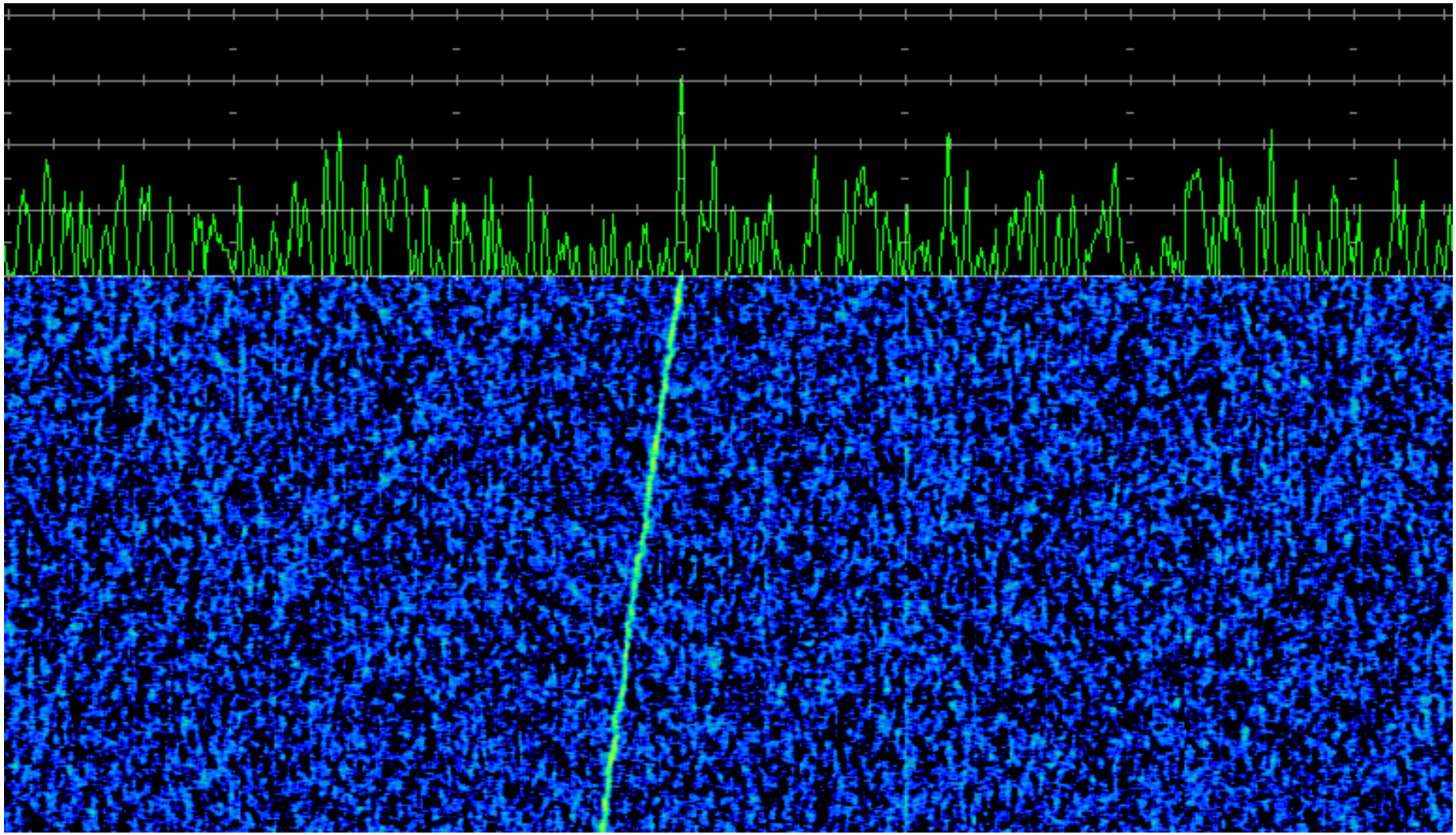
MRO's location from a solar system perspective

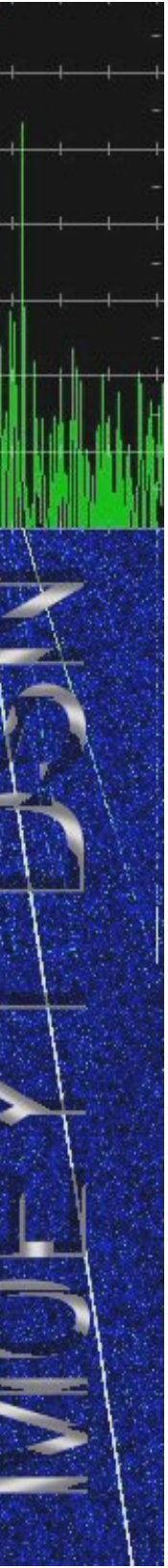


Images copyright NASA / JPL http://deepspace.jpl.nasa.gov

First signals at M0EYT earth station

Signals from MRO were weak, but copyable in FFT





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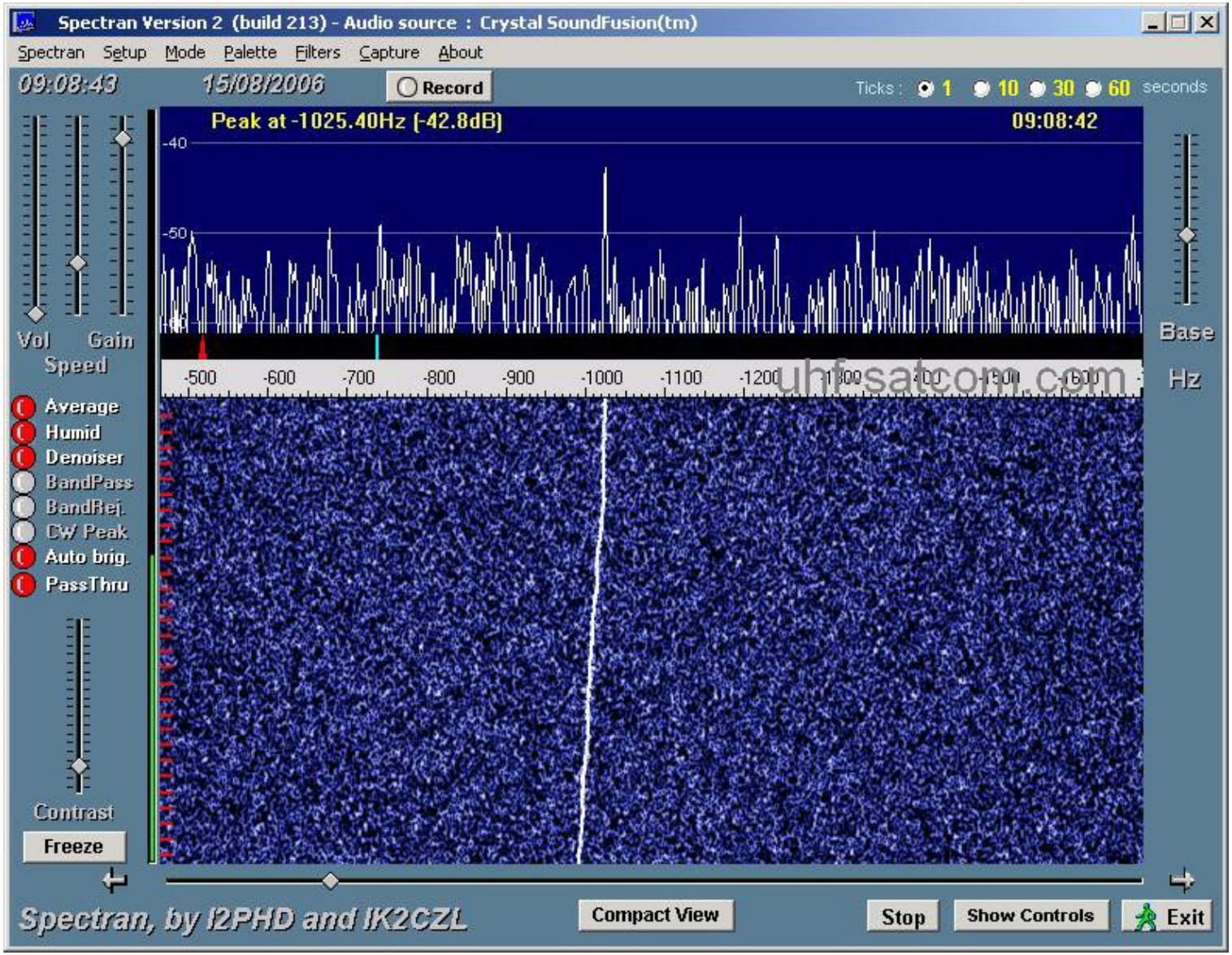
Space Craft DX'd so far

Smart-1: 250000~ miles away 8453.024225 MHz



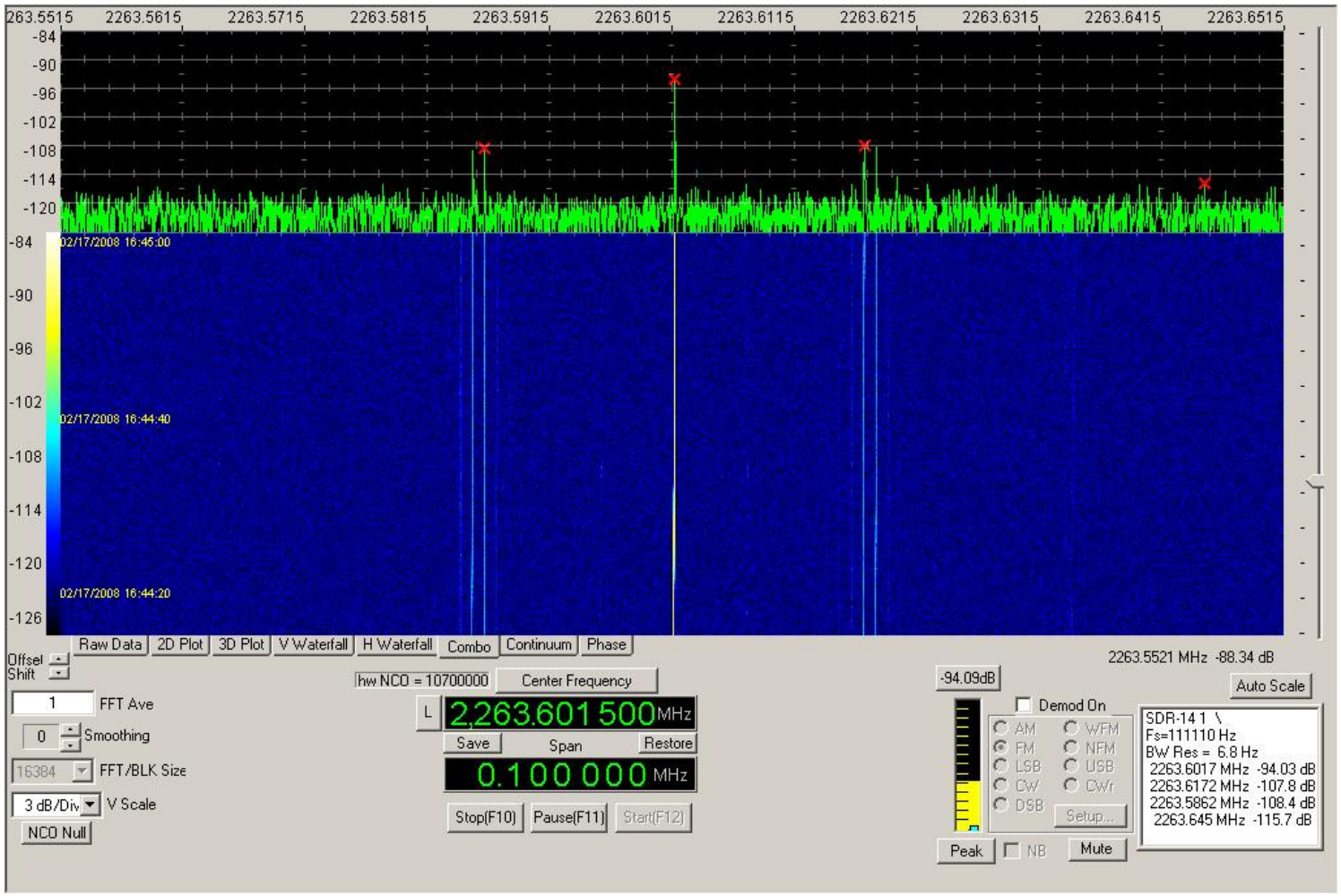
Launched: 27 September 2003

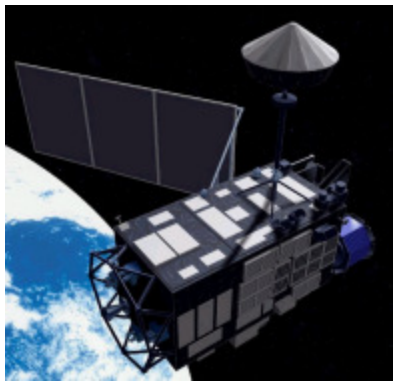
Mission end date: 3rd September 2006 (impact into moon)

RF: Horn antenna with +9dBm ERP at 8453.024225 MHz

Space Craft DX'd so far

JAXA / Selene: 250000~ miles away 2263.6 MHz



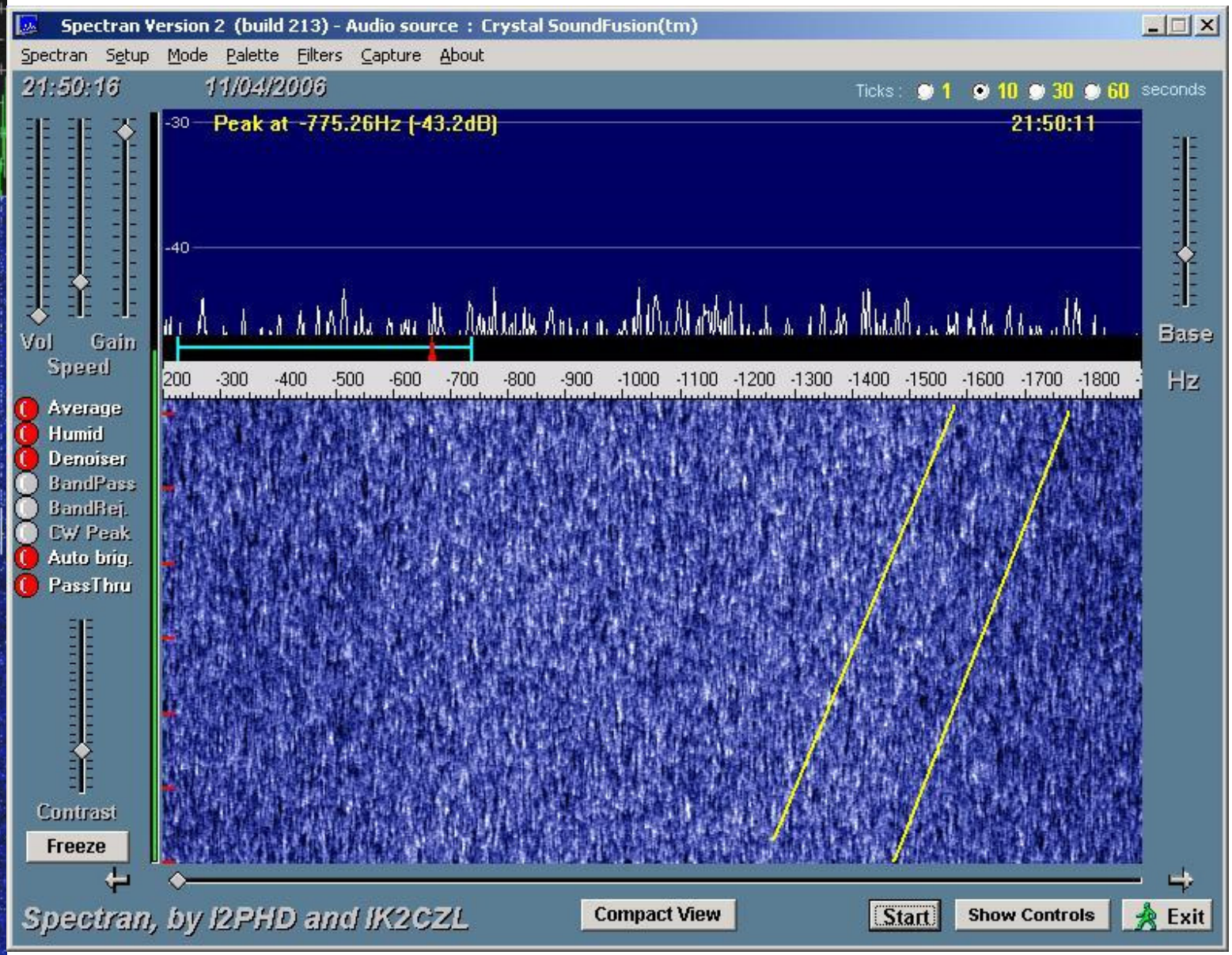


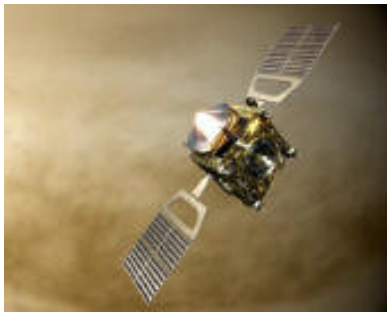
Launched: 14 September 2007

RF: Dish antenna with 4.6W & 25.4dB gain at 2263.6MHz

Space Craft DX'd so far

Mars Odyssey: 180M miles away 8418.921MHz





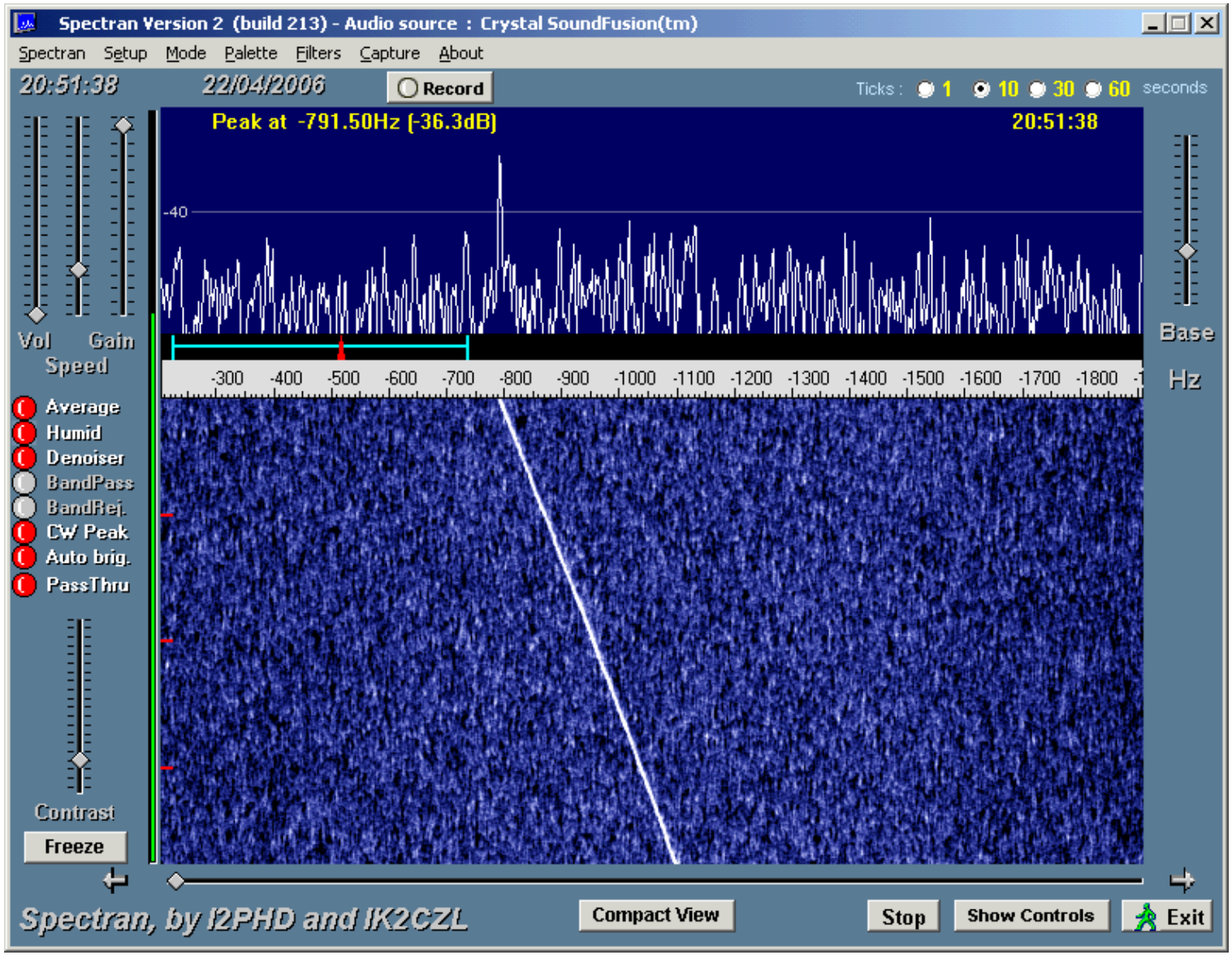
Launched: April the 7th 2001
Arrived Mars on October the 24th 2001

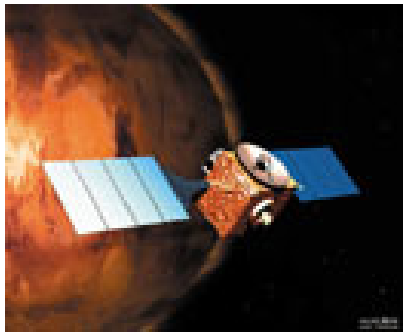
RF: HGA is 1.3m with 15 watts of power at 8406.851853 MHz

ERP: 107151 watts

Space Craft DX'd so far

Mars Express: 180M miles away 8420.432097 MHz





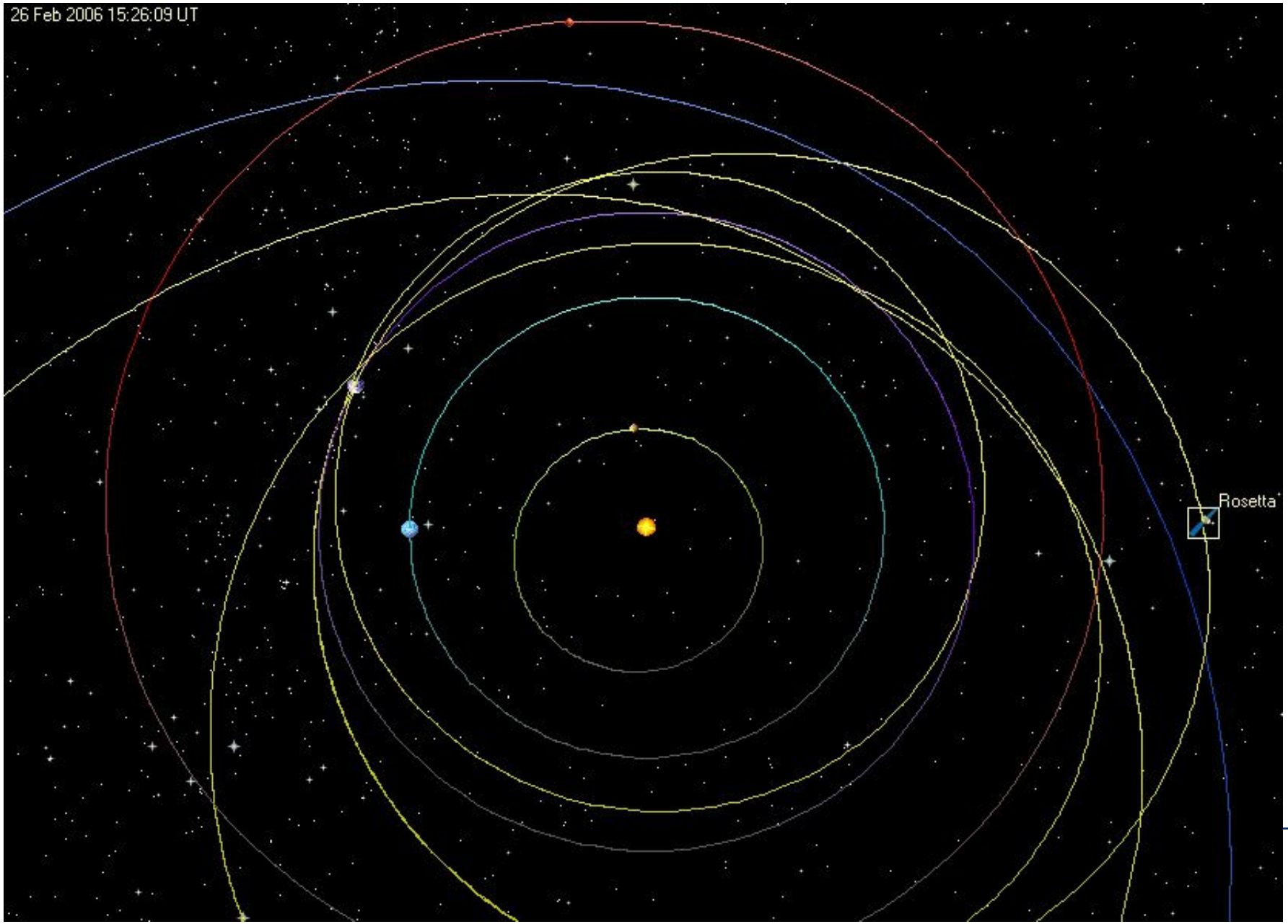
Launched: 2nd 2003
Arrived at Mars in December 2003

RF: HGA is 1.6m
65w of power at
8420.432097 MHz

ERP: 630957 watts

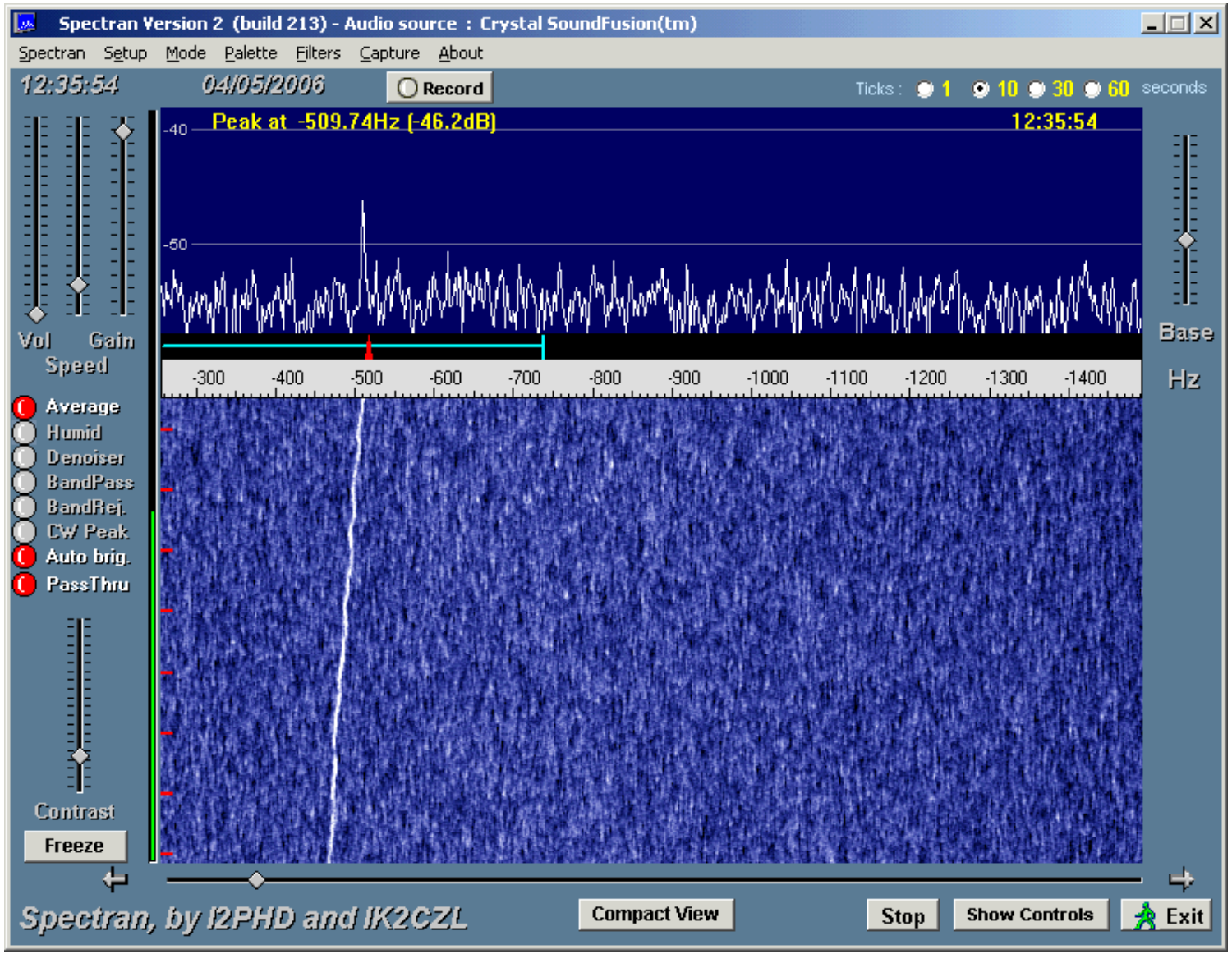
Space Craft DX'd so far

Rosetta: 233830357.56 miles away 8421.790123 MHz



Space Craft DX'd so far

Rosetta: 233830357.56 miles away 8421.790123 MHz



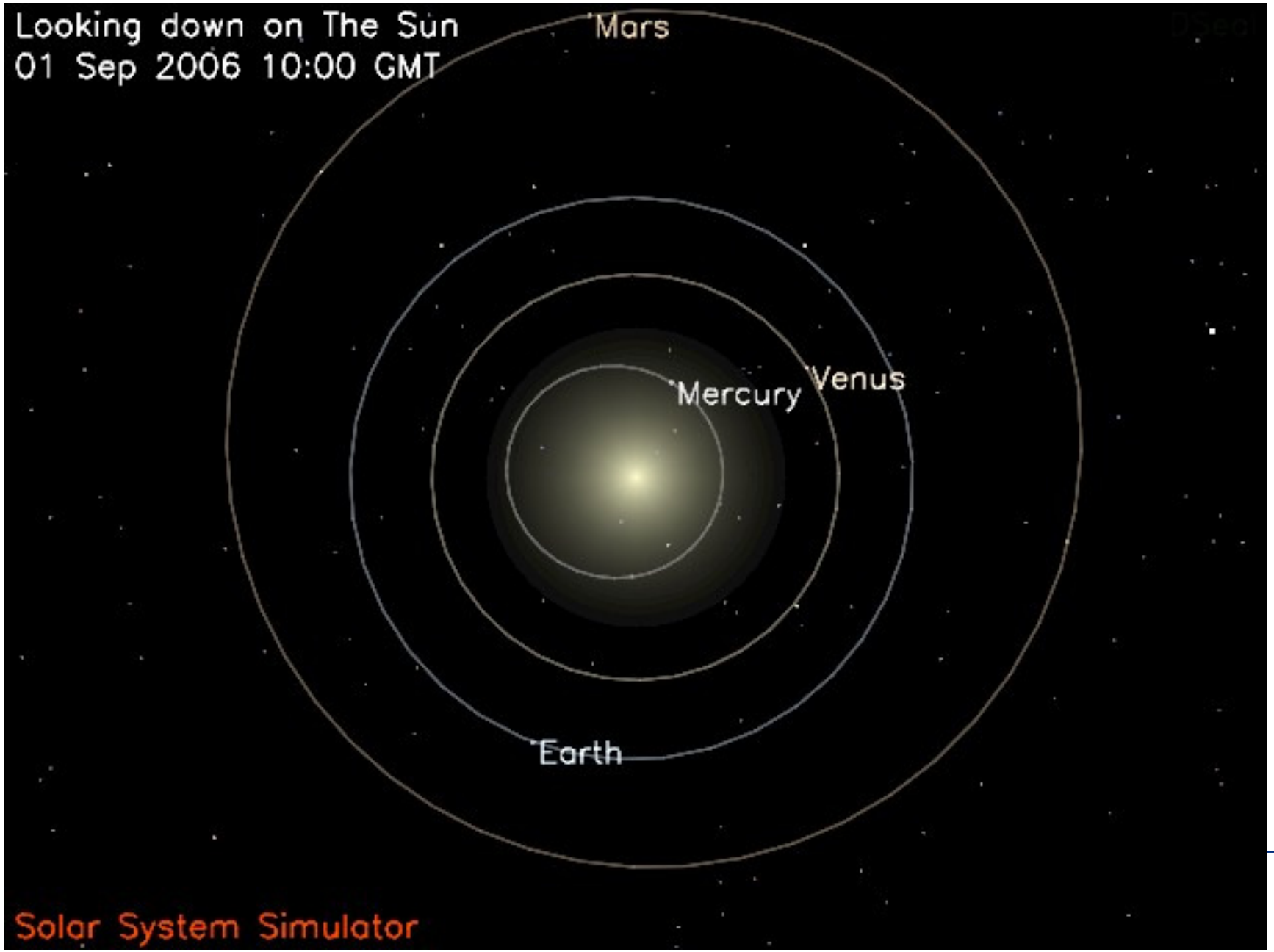
Launched: March the 2nd 2004

RF: HGA is 2.2m with 28 watts of power at 8421.790123 MHz

ERP: 467735 watts

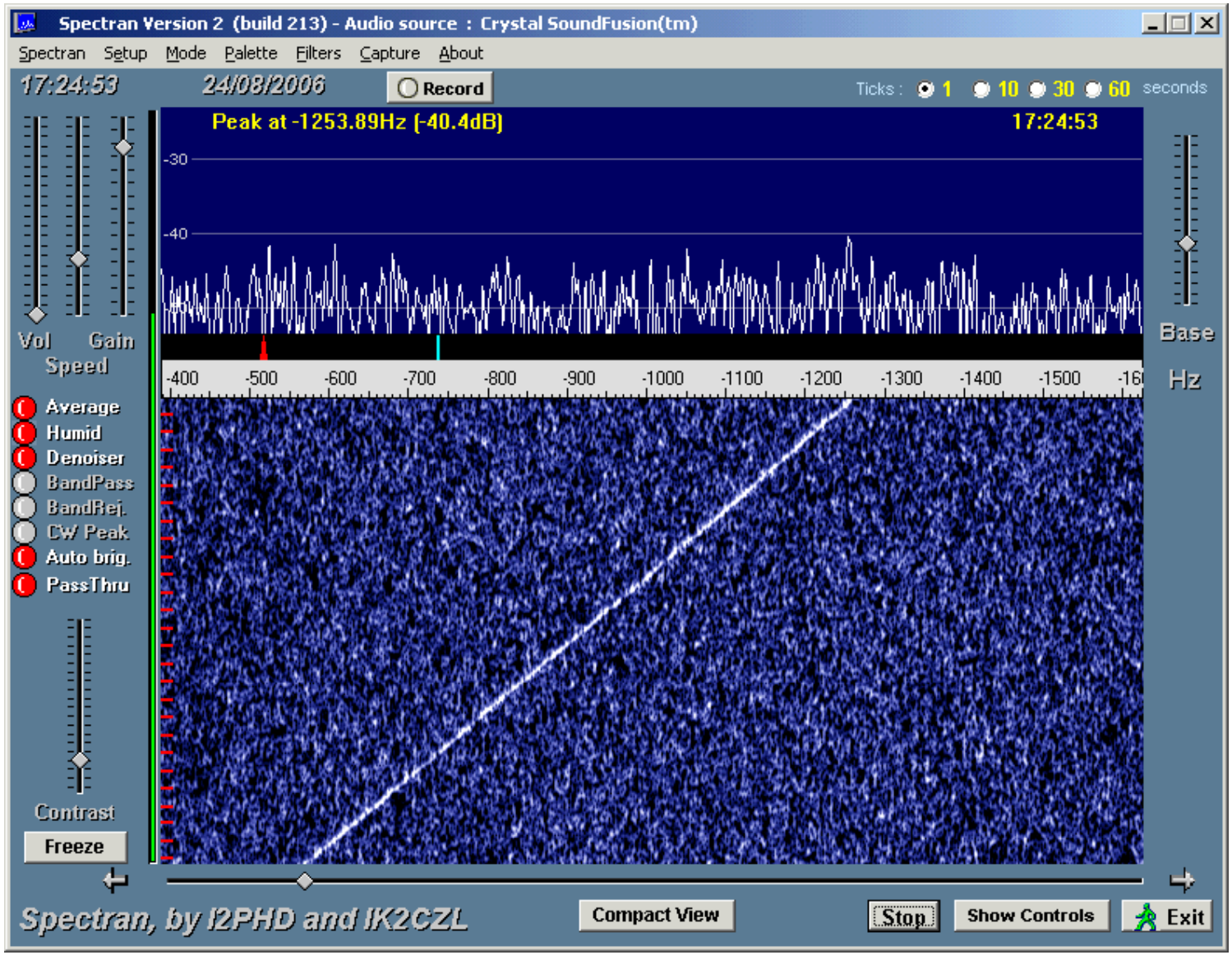
Space Craft DX'd so far

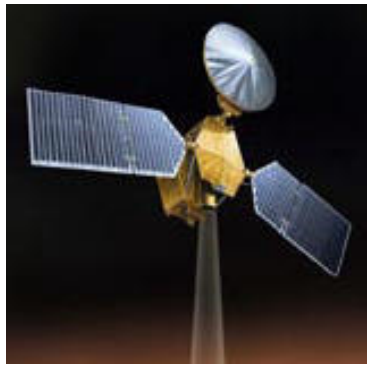
MRO: 238335939.72 miles away 8439.444446 MHz



Space Craft DX'd so far

MRO: 238335939.72 miles away 8439.444446 MHz





Launched : 12th August 2006

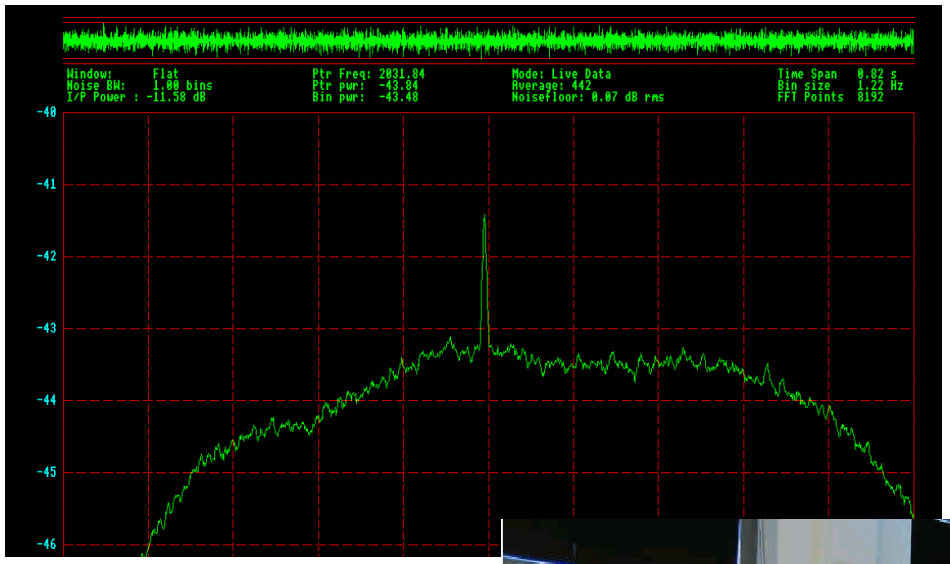
Arrived at Mars on March the 10th 2006

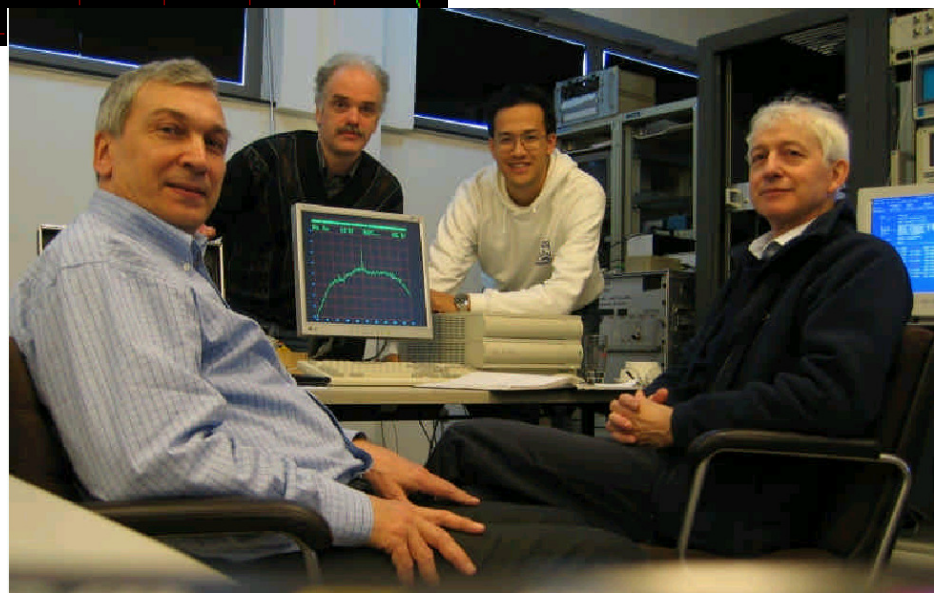
RF: HGA is 3m with 100 watts @ 8439.444446 MHz

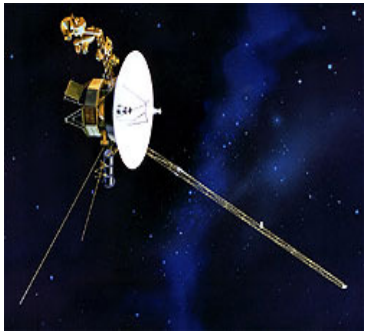
ERP: 3467368 watts

Space Craft DX'd so far

Amsat-DL / IUZ Bochum – Voyager-1
Distance from Earth: 8.82 billion miles



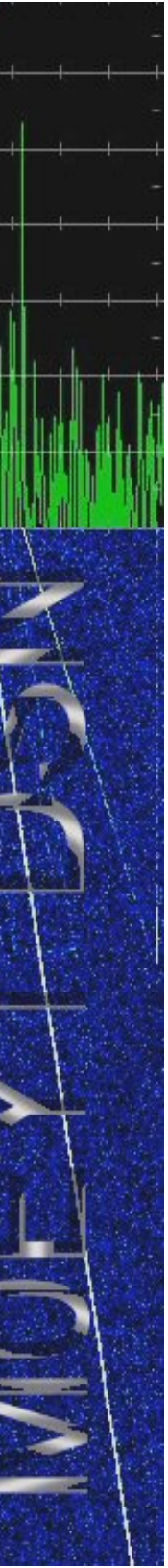




Launched : 5th September 1977

RF: 18 W into 3.74 m dish at 8415MHz and 8420.432097 MHz LHCP

ERP: 1M watts



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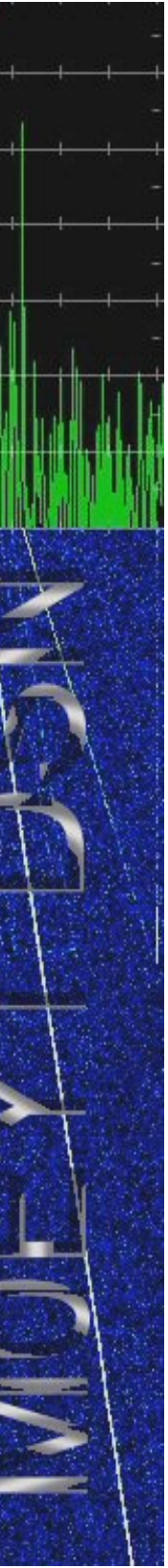


Future

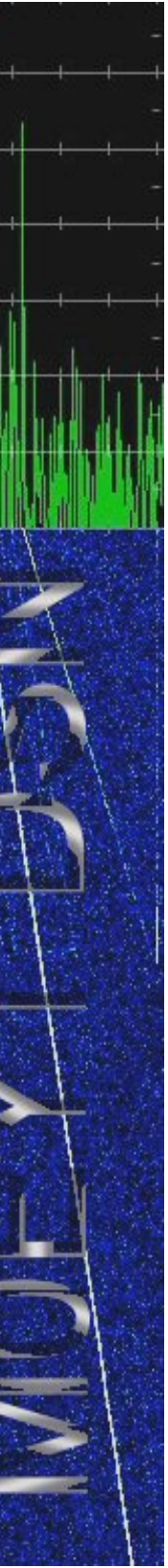
What is the future of A-DSN ?

• New missions are being launched – the most recent is the Chandrayaan 1 lunar orbiter which will TX on S & X band.

• NASA will launch the ‘Lunar Reconnaissance Orbiter’ on April 24, 2009 which will have a Ka Band downlink providing a new opportunity to build hardware.

• A-DSN provides an excellent learning environment to prepare for missions such as the Amsat P5A Mars mission

• Continually weakening signals provide opportunity for system optimisation.



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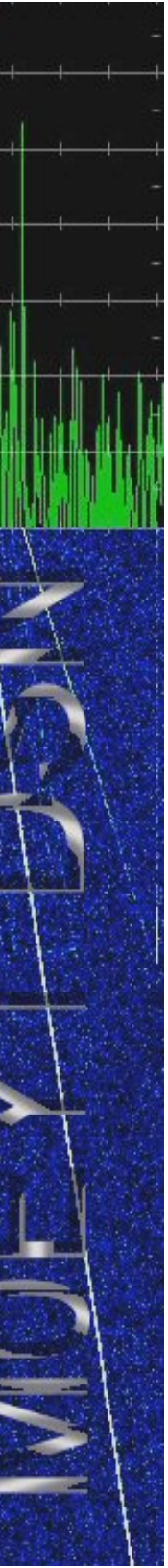

Questions

Any questions – please fire away;

Alternatively, you can contact me at:

pjm@uhf-satcom.com

Further information on Amateur DSN, visit the yahoo group:

http://groups.yahoo.com/group/amateur-DSN

General information on satellite tracking can be found at:
http://www.hearsat.org